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Milling Essentials

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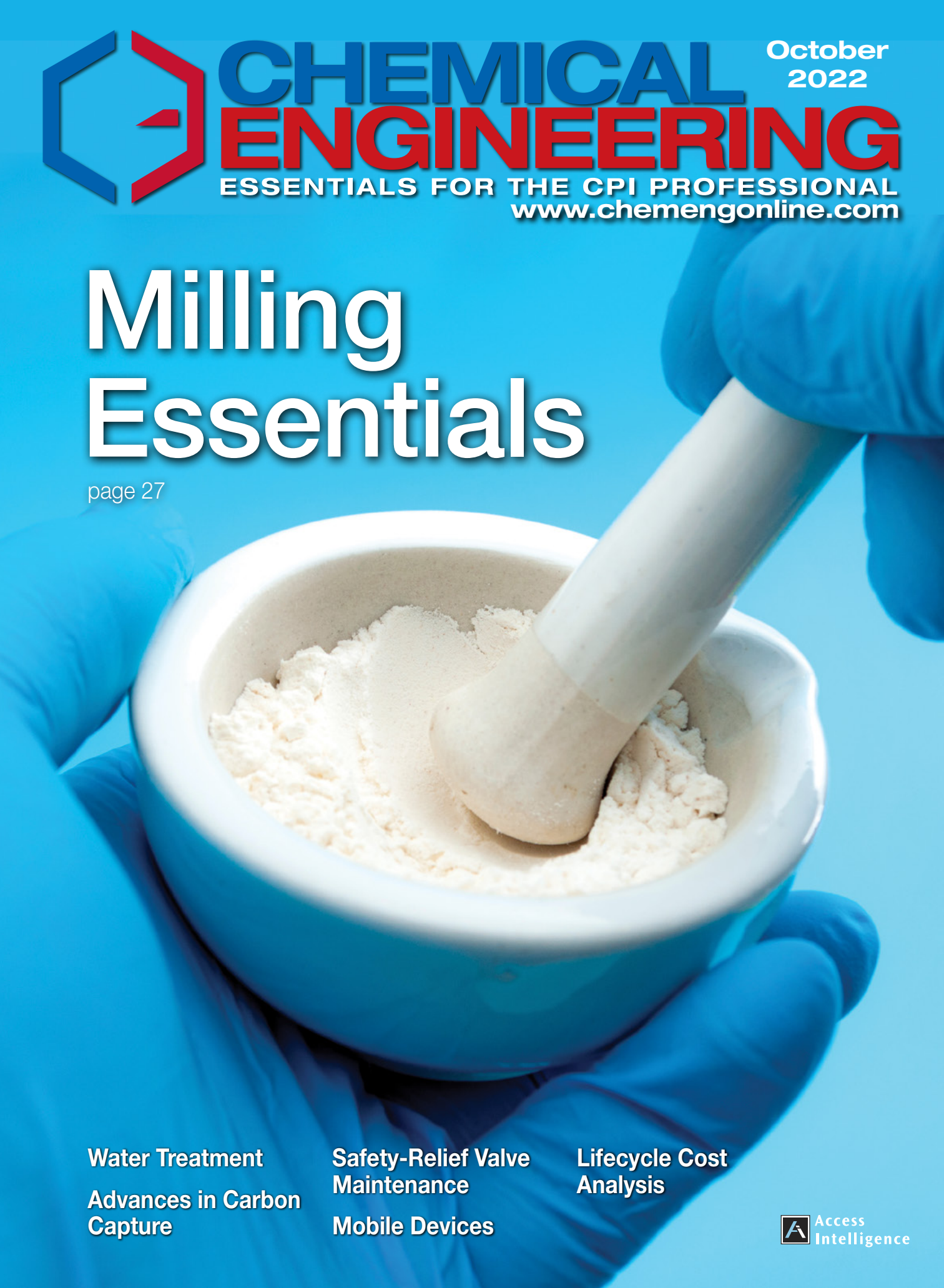

Water Treatment

Advances in Carbon Capture

Safety-Relief Valve Maintenance

Mobile Devices

Lifecycle Cost Analysis

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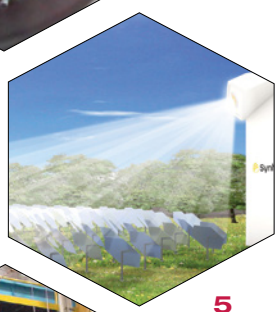

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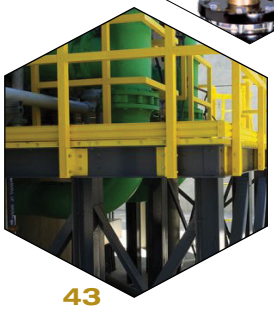

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Editor's Page

Water scarcity worsening

A few months ago, this column addressed the megadrought in the U.S. Southwest and the increasing concerns over water scarcity [*1*]. Since that time, the drought in that region of the U.S. has continued, further impacting communities across the West. And over the course of the summer, severe droughts have been reported across the globe, warranting further attention be given to the impact, as well as the developing technologies, around water scarcity.

Recently released operating plans for Lakes Mead and Powell by the U.S. Bureau of Reclamation (www.usbr.gov) show no signs of lessening drought conditions in 2023. Instead, the plans include additional reductions in water releases from the Glen Canyon and Hoover Dams, which create the two reservoir lakes. The severity of the situation is underscored by recent allocations of government funding to address severe drought conditions, including $8.3 billion for the Bureau of Reclamation's water infrastructure programs [*2*].

A global issue

Increasing concerns over drought conditions have recently been reported around the world. A lack of rainfall and heat over the summer had reduced water levels in many of Europe's rivers. The Rhine river, a major thoroughfare, had experienced low water levels that affected transportation, including that of commercial shipments. A report issued by the European Commission's Joint Research Centre in August [*3*] describes numerous additional upsets from the drought, such as reduced yields on summer farm crops, and severe impacts on energy generation both for hydropower and for cooling capabilities in other power plants.

China is experiencing what is reported to be its worst drought on record, with parts of the Yangtze River drying up. Measures being taken in China include shutting down energy-intensive industries and cloud seeding (Source: *Washington Post*).

Water-treatment technologies

While water-treatment technologies and conservation efforts have been advancing for many years, the current state of severe drought is bringing a renewed urgency to further developments. The U.S. Bureau of Reclamation is, for example, inviting universities, private industries and other sponsors to submit proposals to receive funding for desalination and water-reuse projects. The Bureau says that up to $2 million of funding is available. Details can be found on its website [*4*].

Last month, in what is said to be the largest round of Series A funding ever given to a water-technology company, ZwitterCo, Inc. (www.zwitterco.com) received $33 million in Series A funding to further develop and produce its zwitterionic membrane technology. The company has patented its zwitterionic copolymers [*5*] and describes its product as a "rugged polymeric membrane that is immune to reversible fouling." The funding was led by venture capital company DCVC (www.dcvc.com).

More on water-related technologies can be found in this issue's feature reports, as well as in many of our past issues and on our website. ■

Dorothy Lozowski, Editorial Director

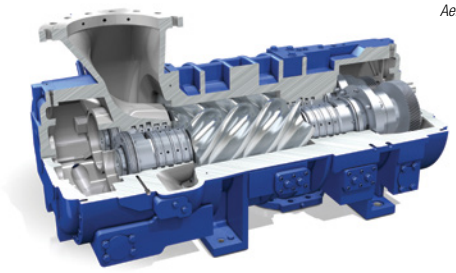
1. Drought emphasizes water scarcity, *Chemical Engineering*, June 2022, p.4.
2. www.doi.gov/priorities/investing-americas-infrastructure/addressing-drought
3. "Drought in Europe, August 2022," https://edo.jrc.ec.europa.eu/documents/news/GDO-EDODroughtNews202208_Europe.pdf
4. www.usbr.gov/newsroom/news-release/4328
5. See "Membranes," *Chemical Engineering*, December 2020, pp.7–8.

Compressing hydrogen from electrolyzers with a single stage

At Achema 2022 (Frankfurt am Main, Germany; August 22–26), a new compressor designed for hydrogen service was launched by Aerzen Maschinenfabrik GmbH (Aerzen, Germany; www.aerzen.com). "We consider this solution to be the game changer in the market," said Michael Leitsch, head of Opportunity Engineering, at a press conference during the exhibition.

One of the challenges in the push for "green" hydrogen is to compress H_2 emerging from atmospheric electrolyzers to higher pressures required for pipeline transport. Because it is so light, H_2 is difficult to compress using conventional compressors, explains Leitsch. Screw compressors, in general, combine the benefits of a turbo compressor and a positive-displacement machine, while requiring a certain clearance between the rotor and the casing. However, for a light gas, such clearances lead to some backflow, which decreases the compressor efficiency.

To overcome this challenge, the new VRW compressor uses a water-flooded converging chamber (diagram). "That means there is actually liquid water in the chamber to cool down the heat of compression. With the reduced thermal expansion of the rotor, we can realize smaller clearances," explains Leitsch. The liquid water also acts as a sealing agent. "With this concept, we are able to increase the efficiency of the compression process significantly, while also managing to realize high discharge pressures," he says.



Aerzen

The small ingress of water into the process is not a problem, because the gas leaving the electrolyzer is already saturated with water. With this design, "we can realize oil-free compression, which is required in this industry," Leitsch says.

The first model, the VRW 536, which was unveiled at Achema, has a suction volume flowrate of 6,000 m^3/h at a suction pressure of 1.0–1.3 bars (typical of atmospheric electrolyzers) and can achieve a discharge pressure of 10 bars. "A conventional dry-screw design would require two compression stages to achieve this pressure," Leitsch says. The company plans to extend the range with the upcoming VRW 736, 836 and 936 models, which will "tremendously increase the volume flows," he says.

CO_2 reduction aided by DNA

Electrochemically reducing carbon dioxide to carbon monoxide offers a pathway to use CO_2 as a feedstock, but the reaction is challenging because it requires catalyst molecules and dissolved CO_2 to meet on the electrode surface. One approach to help this is to link small-molecule catalysts to an electrode surface, but covalent linkages prevent access to the electrode when the catalyst molecules degrade, and non-covalent linkages suffer from uncertain and inconsistent molecule placement (leading to lower catalytic efficiency).

A team of researchers from the Massachusetts Institute of Technology (MIT; Cambridge, Mass.; www.mit.edu) has devised a way to solve these issues by using DNA molecules to firmly and accurately attach the catalyst molecules to the electrode surface in a way that allows the catalyst to be easily removed and replaced when the catalyst molecules degrade.

Led by MIT chemical engineer Ariel Furst, the research team first linked single-stranded DNA to the electrode surface, then used a complementary DNA strand attached to the catalyst to bring the two strands together. The complementary strands hybridize, forming hydrogen bonds between corresponding base pairs and effectively bringing the catalyst to the electrode surface so the reduction reaction can occur. The paired strands of DNA are "stable, but if we heat it up, we can remove the secondary strand with the catalyst on it," says Furst. "That allows us to recycle our electrode surfaces — without having to disassemble the device or do any harsh chemical steps."

To accomplish this, the researchers had to develop a fast and easy method of tethering the DNA to the electrode, then synthesize the complementary strand attached to porphyrin-based catalysts. When the molecules assembled and voltage was applied to the electrode, CO_2 could be efficiently converted to CO, the group says.

Furst hopes to develop a predictive algorithm to help researchers use the DNA approach to design electrocatalytic systems for a wide variety of applications.

Edited by:
Gerald Ondrey

E-CRACKING

Last month, construction began on the world's first demonstration plant for large-scale, electrically heated steam cracker furnaces. The demonstration plant will be fully integrated into one of the existing steam crackers at BASF's *Verbund* site in Ludwigshafen, Germany. It will test two different heating concepts (direct and indirect heating), processing around 4 ton/h of hydrocarbons and consuming 6 MW of renewable energy. The start-up of the demonstration plant is targeted for 2023.

The plant is a collaborative project of BASF SE (Ludwigshafen, Germany; www.basf.com), Sabic (Riyadh, Saudi Arabia; www.sabic.com) and Linde plc (Woking, U.K.; www.linde.com). BASF and SABIC are both investing in the project, and the demonstration plant will be operated by BASF. Linde is the engineering, procurement and construction partner for the project and in the future will commercialize the developed technologies.

To support the development of the new furnace technology, the project has been granted €14.8 million by the German Federal Ministry for Economic Affairs and Climate Action under its "Decarbonization in Industry" funding program.

PLASTIC RECYCLING

This month, after four decades of thermal-conversion technology development, VTT Technical Research Centre of Finland Ltd. (Espoo, Finland; www.research.com) is spinning out a new company — Olefy Technologies Ltd. (www.olefytech.com). The new

(Continues on p. 6)

company offers a patent-pending technology that can extract over 70% virgin-grade plastics and chemical raw materials components from plastic waste. The new process can be done in a single step, significantly reducing the cost of plastic recycling and making recycling a preferred option for massive amounts of landfill-bound plastic waste that current methods are unable to process.

Olefy's thermal-conversion technology eliminates the need for naphtha feedstock in conventional crackers and is also able to produce enough energy for the process. A pilot plant is currently running at VTT Bioruukki Pilot Center in Espoo. The company is currently discussing partnerships and negotiating with investors for scaling, business development, and licensing of the technology. The first industrial demonstration operation is expected to be operational by 2026.

HYDROFORMYLATION

Hydroformylation, the conversion of unsaturated compounds into aldehydes and alcohols using synthesis gas (syngas), is one of the most important reactions in industrial organic chemistry. Until recently, the scientific consensus was that this reaction, if catalyzed with cobalt, could only be carried out under high-pressure conditions without the catalyst decomposing. This has now been disproved by Robert Franke, head of hydroformylation research at Evonik Industries AG (Essen, Germany; www.evonik.com) and professor of chemistry at Ruhr University (Bochum, Germany), together with research partners from the Leibniz Institute for Catalysis (LIKAT; Rostock, Germany; www.catalysis.de). "With this discovery, we have identified new

(Continues on p. 7)

Two milestones for industrial solar-thermal production of fuels

In August, Synhelion S.A. (Lugano, Switzerland; www.synhelion.com) became the first company in the world to produce synthesis gas (syngas) on an industrial scale using only solar heat as an energy source. The milestone occurred on the multifocus solar tower of the German Aerospace Center (DLR; Cologne, Germany; www.dlr.de) in Jülich, Germany. This demonstration was the last technical milestone to overcome for the industrial production of carbon-neutral jet fuels.

The Synhelion team was able to successfully produce solar syngas for the first time in the ETH Zurich laboratory back in 2010. Since then, the challenge has been to scale up the technology to an industrial scale. A cooperation with John Wood Group plc (Wood; Aberdeen, U.K.; www.woodplc.com) has significantly accelerated this technical development. Wood supplies Synhelion with its proprietary reforming reactor in which the syngas is produced. Synhelion now powers this reactor exclusively by solar process heat. To do this, solar radiation is concentrated by a mirror field onto the solar receiver developed by Synhelion in the multifocus solar tower. The tower and the mirror field in Jülich belong to the DLR; the precise mirror-field control technology was developed and installed by Synhelion Germany. Specifically, a 250-kW receiver from Synhelion was coupled with a 6-m-high, 12-ton

reforming reactor at the plant. The system has a production capacity of 100 Nm^3/h. Accordingly, a plant of this size could produce about 150,000 L/yr of liquid solar fuel.

Since then, a groundbreaking ceremony last month officially marked the start of construction on the world's first industrial-scale solar-fuel plant, also in Jülich, which will demonstrate the entire process — from concentrated sunlight to liquid fuels — on an industrial scale. The DAWN plant is being implemented as part of the SolarFuels project, which is funded (€3.92 million) by the German Federal Ministry for Economic Affairs and Climate Action (BMWK). The plant is expected to be commissioned as early as 2023, and Swiss International Air Lines will be the first airline to use the solar kerosene produced by the plant. The demonstration plant will also serve as a model for future commercial plants. By 2030, Synhelion aims to reach a production capacity of 875 million L/yr of fuel in future commercial plants.

Rare-earth recovery from magnet scrap is being scaled up

Rare-earth materials are a crucial part of high-performance magnets in many electronic devices. Right now, only about 5% of these magnets are recycled, but tapping into end-of-life electronics is a promising and more sustainable source for rare-earth materials, the vast majority of which are currently mined in China.

A new pilot plant for recycling rare-earth magnets was recently launched by the University of Birmingham's (U.K.; www.burmingham.ac.uk) Magnetic Materials Group. The plant processes magnets from a variety of end-of-life electronics waste to recover the neodymium, iron and boron they contain, and reform the materials back into commercial-grade magnetic materials. The pilot plant is operating a patented process based on hydrogen decrepitation, called Hydrogen Processing of Magnet Scrap (HPMS), developed at the University of Birmingham. In the process, hydrogen gas is used to break down the magnets into a high-purity NdFeB alloy powder, which is de-magnetized so that it can be further refined and passed to downstream pressing and sintering processes that form the reclaimed materials into new magnets. According to the researchers, this process requires 88% less energy than magnet manufacturing processes using "virgin" materials.

Currently, the pilot facility employs a 1,200-L pressure vessel to process up to 100 kg/d of magnet materials from wind turbines, electric motors, speakers, hard drives and more. Following the successful operation of this pilot plant, plans are underway to scale up the HPMS process for the U.K.'s first full-scale rare-earth recycling and remanufacturing facility, to be completed in 2023 at the Tyseley Energy Park. The HPMS process has been exclusively licensed to HyProMag Ltd., which is also developing a chemical-recycling process for magnet waste to complement HPMS at the new plant. The intent of the new plant will be to produce recycled alloy powders that can be used in any part of the rare-earth value chain.

This inorganic fiber-based paper passively cools buildings, vehicles and much more

A new paper material developed at Northeastern University (Boston, Mass.; www.northeastern.edu) is capable of passive cooling, potentially reducing the energy load required for air conditioning in buildings. "The paper is made from fibers of a calcium-based material called hydroxyapatite. The fibers are randomly oriented in a sheet, enabling high scattering of incident light, which results in the near-perfect reflection of solar radiation," explains Yi Zheng, a professor at Northeastern's College of Engineering. The material has a high emittance in the infrared wavelength region of 8–13 μm — at these wavelengths, the Earth's atmosphere allows a high amount of radiation to escape rather than being reflected or re-absorbed by the atmosphere. "The high solar reflectance of the material limits heat input, while the high infrared emittance maximizes the heat emitted by the material. By combining these two properties, the cooling paper allows structures to be cooled below the ambient temperature, even on extremely sunny days," adds Zheng.

The hydroxyapatite fibers are produced using a precipitation method, where a mixture is heated within a pressure vessel for about 24 h. Once the fibers are filtered from the mixture, they are incorporated into a roll-to-roll process similar to how sheets of paper are made. The final product is a durable sheet of the hydroxyapatite cooling material. Both of these processes are used at the industrial level already, so the processes are compatible with large-scale production. Furthermore, other passive-cooling methods, including specialized paints or polymers, may include constituents that are environmentally harmful, whereas hydroxyapatite fibers are biocompatible. In addition, this inorganic paper has intrinsic properties — fire resistance and self-cleaning capabilities — which are highly demanded for outdoor applications.

So far, the team has demonstrated the cooling method at the laboratory scale using 100-mm-wide samples. Zheng, along with Ph.D. researcher Andrew Caratenuto, have formed a startup company called Plank Energies, through which they plan to commercialize the paper. "We are focused on scaling fabrication with commercial partners and optimizing the material for large-scale use," adds Zheng.

process options for hydroformylation," says Evonik's Franke.

As described in a recent issue of *Science*, the researchers succeeded in demonstrating, for the first time, that cobalt carbonyls — very inexpensive compounds for the catalysis of hydroformylation — are active and stable even at low pressures. The key to this discovery was the development of special spectroscopic measurement methods and associated mathematical tools for data evaluation. High-pressure processes that use cobalt carbonyls as catalysts could be replaced in the future by new processes with lower pressures. These new processes would then be more cost-effective, energy-efficient and thus more sustainable.

(Continues on p. 8)

MARINE AGRICULTURE

BASF Venture Capital GmbH (www.basf-vc.com), the corporate venture company of BASF, and Aqua-Spark (Utrecht, the Netherlands; aqua-spark.nl) are investing in Sea6 Energy Pvt. Ltd. (Bangalore, India; www.sea6energy.com) as part of a Series B round. Sea6 Energy was founded in 2010 and is a leader in the production and processing of tropical red seaweed. Other existing investors include Tata Capital Innovations Fund. With this investment, Sea6 Energy will complete its Series B transaction of INR1,402 million (about $18.5 million) in total.

Red seaweed grows mainly in tropical waters in Asia, which have constant high temperatures conducive to year-round growth of seaweed. Biomass from the fast- growing red seaweed is suitable as a raw material for a variety of applications, for example in animal-feed and crop-protection products, as a gelling ingredient in the food industry or as an ingredient in cosmetics.

In Bali, Indonesia, Sea6 Energy has set up a fully owned subsidiary that carries out commercial seaweed farming. The company also operates various plants in Tuticorin, India for the further processing of red seaweed for different applications. Sea6 Energy is also working on the development of bioplastics and biofuels based on red seaweed. In addition, the company has developed a proprietary process that increases the shelf life of red seaweed from 1 to 2 days to up to 60 days.

LITHIUM RECOVERY

Evonik has developed a conductive ceramic membrane that can be used in an electrochemical cell to selectively recover lithium. The technology, developed at the company's Marl and Hanau sites, offers an economical way to recycle lithium-ion batteries, which are increasingly being used in electric cars. Current hydrometallurgical (leaching) and pyrometallurgical (smelting) methods have been limited to recovering only nickel and cobalt from LIBs, because it is not cost-effective to also recover the lithium. Evonik's new electrochemical route processes the leftover leachate from conventional recycling methods, and produces battery-grade $LiOH{\cdot}H_2O$ at the cathode. Li-recovery of more than 99% has been achieved in laboratory trials. The technology is currently being tested on a pilot scale. The ceramic membrane process will be market-ready in three to five years, the company says.

(Continues on p. 9)

Engineering soybean plants to increase crop yield

For the first time, researchers have proven that multigene bioengineering of photosynthesis increases the yield of the major food crop soybean in field trials. An international collaborative team of the RIPE project (Realizing Increased Photosynthetic Efficiency), led by the University of Illinois Urbana-Champaign (https://illinois.edu), has transgenically altered soybean plants to increase the efficiency of photosynthesis, resulting in greater yields without loss of quality.

Photosynthesis, the natural process all plants use to convert sunlight into energy and crop yield, is a surprisingly inefficient, 100-plus step process that RIPE researchers have been working to improve for more than a decade. In this first-of-its-kind work, recently published in *Science*, the group improved the "VPZ construct" within the soybean plant to improve photosynthesis and then conducted field trials to see if yield would be improved as a result.

The VPZ construct contains three genes that code for proteins of the xanthophyll cycle, which is a pigment cycle that helps in the photoprotection of the plants. Once in full sunlight, this cycle is activated in the leaves to protect them from damage, allowing leaves to dissipate the excess energy. However, when the leaves are shaded (by other leaves, clouds, or the sun moving in the sky) this photoprotection needs to switch off so the leaves can continue the photosynthesis process with a reserve of sunlight. It takes several minutes for the plant to switch off the protective mechanism, costing plants valuable time that could have been used for photosynthesis.

The overexpression of the three genes from the VPZ construct accelerates the process, so every time a leaf transitions from light to shade the photoprotection switches off faster. Leaves gain extra minutes of photosynthesis which, when added up throughout the entire growing season, increases the total photosynthetic rate. This research has shown that despite achieving a more than 20% increase in yield, seed quality was not impacted.

Batteries not required for this smart gas mask

Researchers from Chung-Ang University (Seoul, South Korea; https://neweng.cau.ac.kr) have developed a triboelectric nanogenerator (TENG) that is operable via breathing and can, therefore, be integrated into gas masks. The device is capable of powering LEDs and Bluetooth trackers, and can monitor breathing patterns and chemical warfare agents.

The device, described in a recent issue of *Advanced Energy Materials*, is an inhalation-driven vertical flutter TENG (IVF-TENG), which exhibits an amplified current output. Respiration acts as a continuous mechanical input and can be used to operate TENGs, which convert the mechanical energy into electrical energy. The IVF-TENG is composed of an aluminum inlet electrode, an aeroelastic dielectric sheet (polyimide) and an Al outlet electrode. The aeroelastic sheet has four segments with four slits and is subjected to vertical flutter behavior caused by airflow. This makes the proposed IVF-TENG different from existing TENGs.

The researchers found that IVF-TENG generated a continuous, high-frequency electrical voltage (17 V) and a closed-circuit current of 1.84 μA during inhalation, and an electrostatic discharge voltage of 456 V and closed-circuit output current of 288 mA at the beginning and end of every inspiratory cycle. They further demonstrated that IVF-TENG can continuously power 130 LEDs in series and 140 LEDs in parallel in every inhalation. Additionally, it could charge a 660 μF capacitor to, in turn, power a Bluetooth tracker and provide its signal to a smartphone. These properties demonstrated the potential for IVF-TENG's application in portable electronics and wireless data transmission. Furthermore, the researchers integrated IVF-TENG into a gas mask and demonstrated its ability to monitor the breathing pattern of the user by observing the output response waveform. Moreover, it could detect chemical warfare agents, such as cyanogen chloride, sarin and dimethyl methylphosphonate, showing its potential for use during emergencies.

Carbonized polymer membrane exhibits improved performance, stability

Organic-solvent nanofiltration (NF) uses membranes with tiny pores to remove dissolved molecules. "Although NF is more energy efficient than alternative separation methods, such as distillation, the majority of polymer-based membranes exhibit poor chemical stability," says Rifan Hardian, a post-doctoral researcher at King Abdullah University of Science and Technology (KAUST; Thuwal, Saudi Arabia; www.kaust.edu.sa). These membranes typically need additional chemical crosslinkers to improve their stability, which complicates their manufacture. Many membranes, as they swell and age, also tend to lose their performance and they may even break down to release trace contaminants.

Hardian and his colleagues have now overcome these drawbacks by creating a new kind of carbon molecular sieve (CMS) membrane that does not require additional crosslinkers. According to the recent paper in *Applied Materials Today*, the membranes were prepared using a polyimide of intrinsic microporosity (PIM), known as 4,4'-(hexafluoroisopropylidene) diphthalic anhydride (6FDA)-3,3'-dimethylnaphthidine (DMN), via a phase inversion technique. The 6FDA-DMN can be formed into a flat, porous membrane with good thermal stability. Baking the polymer at 400–600°C for several hours resulted in a tough membrane made entirely of carbon. Electron microscope images showed that at the highest temperatures, this carbonization process also shrank the membrane's pores considerably.

The molecular-sieving performance of the membranes was investigated using five solvents with different polarities. The membranes showed no swelling and high stability in strong acids, bases and organic solvents, as well as an excellent rejection profile and reasonable permeance, the researchers report.

The researchers are now working to improve the membrane's permeance and plan to incorporate various nanomaterials into the membrane to control its properties. ■

RHODIUM(VII)

Mayara da Silva Santos, doctoral candidate at the University of Freiburg's Institute of Physics (Germany; www.physik.uni-freiburg.de), has discovered a new oxidation state of rhodium, an important catalyst of the platinum-group metals. This highest oxidation state of rhodium — rhodium(VII), or Rh^{7+} — was previously unknown, but could play a role in chemical reactions.

As part of her doctoral dissertation, Silva Santos is studying unusual transition metal oxides. "Our oxides are highly reactive but could play an important role as reactive intermediate states," she says. They can be observed in chemical reactions only with difficulty because they are very short-lived. "We were able to store the oxides in a special ion trap at low temperatures over an extended time period and thus study them undisturbed."

The discovery was published in a recent issue of *Angewandte Chemie International Edition* ❐

LINEUP

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Plant Watch

Gevo breaks ground on commercial-scale SAF facility in South Dakota

September 16, 2022 — Gevo, Inc. (Englewood, Colo.; www.gevo.com) announced the groundbreaking in South Dakota of its first commercial-scale sustainable aviation fuel (SAF) facility, Net-Zero 1 (NZ1). This project is expected to begin delivery of initial volumes (some 55 million gal/yr) of SAF in 2025.

Toray announces new non-woven materials facilities in the Czech Republic

September 16, 2022 — Toray Industries, Inc. (Tokyo; www.toray.com) announced that its subsidiaries Toray Textiles Central Europe s.r.o. (TTCE) and Toray Advanced Materials Korea Inc. (TAK) have set up new facilities in the Czech Republic to expand production of the Airlite line of melt-blown, sound-absorbing non-woven materials made of lightweight polypropylene and polyester. This new plant will have a production capacity of 1,200 metric tons per year (m.t./yr).

Solvay to expand rare-earth operations hub in France

September 16, 2022 — Solvay S.A. (Brussels, Belgium; www.solvay.com) plans to expand its rare-earth-metals operations in La Rochelle, France to enter the value chain for rare-earth permanent magnets in Europe. This new investment will expand and upgrade an existing unit to add the production of separated rare-earth oxides for permanent magnets to the site. At the same site in La Rochelle, Solvay also recently opened a new pilot plant to scale up the development of advanced inorganic materials for solid-state battery electrolytes.

Siemens commissions one of Germany's largest 'green' hydrogen plants

September 15, 2022 — Siemens Energy (Munich, Germany; www.siemens-energy.com) has commissioned one of Germany's largest green hydrogen-generation plants. Up to 1,350 ton/yr of green hydrogen can now be generated from renewable solar and wind power at the Wunsiedel Energy Park. Hydrogen is produced using an 8.75-MW electrolyzer.

ALPLA and PTTGC open plastics-recycling plant in Thailand

September 14, 2022 — ALPLA Group (Hard, Austria; www.alpla.com) and PTT Global Chemical (Bangkok, Thailand; www. www.pttgcgroup.com) have opened a new recycling plant in Thailand. The plant has production capacity of 30,000 m.t./yr of recycled polyethylene terephthalate (PET) and 15,000 m.t./yr of recycled high-density polyethylene (HDPE).

Dow and Mura Technology to locate new advanced-recycling facility in Germany

September 14, 2022 —Dow (Midland, Mich.; www.dow.com) and Mura Technology Ltd. plan to build a new advanced recycling plant at Dow's site in Böhlen, Germany. The new plant, which is expected to be operational by 2025, would deliver approximately 120,000 m.t./yr of advanced recycling capacity at full rate.

Milliken launches production at clarifier plant in South Carolina

September 13, 2022 — Milliken & Co. (Spartanburg, S.C.; www.milliken.com) recently launched production at its new clarifier plant in Blacksburg, S.C. Once the plant reaches full operating capacity, which is expected by the end of 2022, Milliken will increase its volume of Millad additives by 50%.

Linde to build new PEM electrolyzer in Niagara Falls, N.Y.

September 8, 2022 — Linde plc (Guildford, U.K.; www.linde.com) will build a 35-MW proton exchange membrane (PEM) electrolyzer to produce green hydrogen in Niagara Falls, N.Y. The new plant will be the largest electrolyzer installed by Linde globally and will more than double Linde's green liquid-hydrogen production capacity in the U.S. The plant is expected to start up by 2025.

BASF inaugurates first plant of new Zhanjiang Verbund site

September 7, 2022 — BASF SE (Ludwigshafen, Germany; www.basf.com) is inaugurating the first plant of its new Zhanjiang *Verbund* site in the province Guangdong in South China. The plant will provide a capacity of 60,000 m.t./yr of engineering plastics compounds.

Ashland is expanding production of bioresorbable polymers in Ireland

September 1, 2022 — Ashland Global Holdings Inc. (Wilmington, Del.; www.ashland.com) announced a significant expansion of its Viatel bioresorbable polymer site in Mullingar, Ireland. The capital expansion program is expected to be complete in 2024. Ashland supplies more than 70 grades of lactide, glycolide and caprolactone copolymers within its Viatel product portfolio.

Ube is raising polycarbonate diol production capacity at Thai subsidiary

September 1, 2022 — Ube Corp. (Tokyo) started a third expansion of its production facilities for polycarbonate diol (PCD) at one of its local subsidiaries in Thailand. The facility will start operations in August 2023, and the production capacity is planned to be increased from 8,000 m.t./yr to 12,000 m.t./yr.

Mergers & Acquisitions

Henkel completes acquisition of two Boston-based businesses

September 15, 2022 — Henkel AG & Co. KGaA (Düsseldorf, Germany; www.henkel.com) completed the acquisition of the Thermal Management Materials business of Nanoramic Laboratories (Boston, Mass.), which is marketed under the name Thermexit. The Thermexit portfolio includes patented thermal-interface gap pads based on a nano-filler technology. Henkel also recently completed the acquisition of the advanced materials startup NBD Nanotechnologies Inc. (Boston). NBD Nano has expertise in developing surface properties, such as repellency for plastics or optical coatings for displays.

Air Liquide divests its industrial merchant business in Saudi Arabia

September 13, 2022 — Air Liquide S.A. (Paris, France; www.airliquide.com) sold its industrial merchant business in Saudi Arabia to Air Products' (Lehigh Valley, Pa.; www.airproducts.com) merchant industrial gas joint venture (JV) in Saudi Arabia. This transaction includes Air Liquide's share in Air Liquide Khafra Industrial Gases. This divestment complements the previously announced sale of Air Liquide's industrial merchant business in the U.A.E. and Bahrain to Air Products.

Kemira to sell colorants dye business to ChromaScape

September 12, 2022 — Kemira Oyj (Helsinki, Finland; www kemira.com) agreed to sell its colorants and dye business to ChromaScape, LLC. The scope of the sale, which is expected to close in early 2023, includes a Kemira manufacturing site in South Carolina. The divested business includes dyes, organic pigments and special colorants.

Evonik sells RheinPerChemie business to Calibre Chemicals

September 7, 2022 — Calibre Chemicals (Mumbai, India) will acquire the entirety of RheinPerChemie GmbH (RPC), from Evonik Industries AG (Essen, Germany; www.evonik.com). RPC, located in Rheinfelden, Germany, is a prominent manufacturer of ammonium and sodium persulfates in Europe.

Clariant sells Quats business for $113 million

August 31, 2022 — Clariant AG (Muttenz, Switzerland; www.clariant.com) reached a definitive agreement for the divestment of its quaternary ammonium compounds business (Quats) to Global Amines Co. (Singapore; www.globalamines.com), a 50-50 JV owned by Clariant and Wilmar. The $113-million sale involves sites in Germany, Indonesia and Brazil. Quats are used for preservatives, surfactants and antistatic agents.

Ineos to acquire Mitsui Chemicals' phenols business in Singapore

August 30, 2022 — Ineos Ltd. (London, U.K.; www.ineos.com) announced that Ineos Phenols will acquire Mitsui Phenols Singapore Ltd. from Mitsui Chemicals, Inc. (Tokyo; www.mitsuichemicals.com) for $330 million. The acquired business produces several chemical products, including: cumene (410,000 m.t./yr); phenol (310,000 m.t./yr); acetone (185,000 m.t./yr); alpha-methylstyrene (20,000 ton/yr); and bisphenol A (150,000 m.t./yr). ■

Mary Page Bailey

Advancing Industrial Carbon Capture

An expanding array of CO_2-capture approaches are quickly developing for hard-to-abate industrial sectors. The key objective is to significantly lower the costs of traditional CO_2-capture techniques, which are based on aqueous alkanolamine absorption and desorption

Achieving climate mitigation objectives, such as carbon neutrality by 2050, requires aggressive large-scale deployment of CO_2 capture, utilization and storage (CCUS) technologies. A critical piece of the broad CCUS universe involves capturing CO_2 emitted from industrial plants where full and immediate decarbonization is technologically unfeasible or cost-prohibitive in the near- to mid-term. Such facilities include natural-gas power plants, cement- and steel-making plants, among other heavy industry sectors. The current decade is increasingly viewed as critical for reducing CO_2 emissions, placing further importance on developing and applying cost-competitive CO_2 capture.

Because the largest fraction (estimated at up to 70–80%) of the costs associated with CCUS solutions involve capturing the CO_2 and separating it from the capture medium, research and development efforts on a large number of different carbon-capture approaches are currently focused on reducing costs. Specifically, researchers, engineers and technology developers from the public and private sectors are teaming up to test various technologies to minimize or offset the parasitic energy penalty associated with CO_2 capture, while also improving process performance.

These efforts have been boosted recently by private investment, government funding programs and legislation, such as the recent Inflation Reduction Act in the U.S, which broadened tax credits for carbon sequestration, among other policy initiatives. In August, the U.S. Department of Energy's (DOE) Office of Fossil Energy and Carbon Management (FECM) announced more than $31 million in funding for 10 projects to develop carbon capture technologies capable of capturing at least 95% of CO_2 emissions generated from natural-gas power plants, waste-to-energy power plants, and industrial applications, including cement and steel.

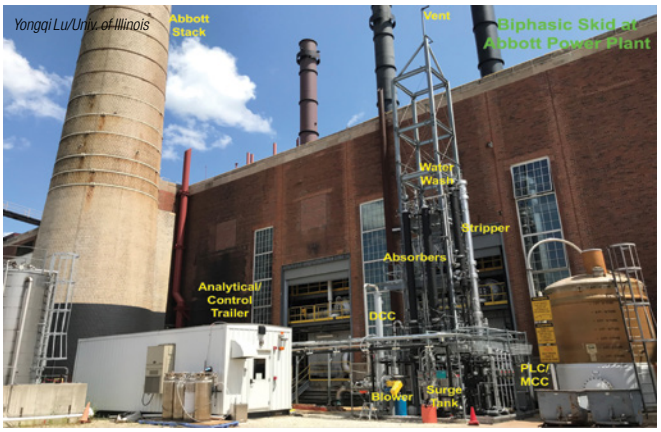

FIGURE 1. University of Illinois researchers built this pilot unit to test and develop a biphasic amine solvent that lowers energy requirements for CO_2 capture

The diversity of industries to which CO_2 capture could be applied, combined with differences in fluegas compositions and process configurations, will likely mean that many different post-combustion carbon-capture technologies will be required throughout heavy industrial sectors to meet variable CO_2-mitigation needs that may fit best with one technology approach more than others.

Phase separation

Traditional technology for post-combustion carbon capture is largely based on using alkanolamines, such as monoethanolamine (MEA), or similar solvents. The process works by introducing CO_2-containing fluegas into the bottom of an absorber tower, where it flows upward against a down-flowing aqueous amine stream, which removes CO_2 from the fluegas. The solvent is then regenerated and the CO_2 captured in a desorber at differing temperature or pressure conditions. One approach to reducing the energy requirements, and with it, the costs, of CO_2 capture involves phase-separation schemes.

Researchers from the Prairie Research Institute (PRI; prairie.illinois.edu) at the University of Illinois at Urbana-Champaign have developed a novel biphasic solvent-based CO_2 absorption process (known as BiCAP) that has the potential to lower energy and equipment costs for regenerating the CO_2 from the solvent, once it is absorbed. The technology is based on a blended solvent that separates according to hydrophilicity and density into a CO_2-rich phase and CO_2-lean phase after contacting the fluegas. Most (~95%) of the CO_2 absorbed ends up in the rich phase, which is about half (or less) of the volume of the original solvent, notes principal investigator Yongqi Lu, a chemical and environmental engineer at PRI. Because almost all the CO_2 is contained in half the volume of solvent, less energy is required for thermal desorption, and the stripping capacity is increased, due to

FIGURE 2. University of Kentucky researchers are testing a dual-loop CO2-capture system that generates hydrogen to offset the cost of the capture

the higher CO_2 loading in the "rich" solvent phase. In addition, less energy and compression work are required to compress the CO_2, which is desorbed at an elevated pressure, according to the research team.

The group tested the process at a 0.7-ton/day integrated small pilot-scale capture unit at Abbott Power Plant in early 2022 (Figure 1) and validated the improved energy performance over the conventional absorption process. The team is planning is to scale up the technology at the 2–20 ton/day scale at industry sites.

Another angle on the phase-separation idea, known as the DMX process, comes from IFP Energies Nouvelles (www.ifpenergiesnouvelles.fr) and Axens (both Rueil-Malmaison, France; www.axens.net). DMX, a patented process stemming from research at IFP and being marketed by Axens, uses a solvent that reduces the energy intensity for carbon capture by nearly 30% compared to the MEA reference process. DMX is based on absorption by a de-mixing solvent (the DMX solvent), which is specifically designed to separate, under specific temperature and CO_2 partial-pressure conditions, into a water-rich phase with high CO_2 loading, and an amine-rich phase that is low in CO_2, IFP says. The separation reduces the flow to the stripper, so less regeneration energy is required.

The DMX process was developed for CO_2 capture on coal-power-plant fluegas and steel-making offgas, as well as waste incinerators, cement plants and biomass energy plants.

In May of this year, CarbonOrO Products B.V. (Naardem-Vesting, the Netherlands; www.carbonoro.com) received support from a cement industry consortium (Global Cement and Concrete Association) to develop its technology, which uses a proprietary CO_2-capture amine solvent that is designed to undergo a phase shift. Due to the unique properties of the biphasic solvent, desorption of CO_2 is not just driven by chemistry, but also by a physical process (phase-shift), the company says. This allows for desorption of CO_2 at much lower temperatures (starting at ~70°C) than prevailing amines solvents (starting at ~130°C). "Also, CO_2-evasion is more or less instantaneous instead of gradual and correlated to temperature," the company says. Consequently, energy use by the CarbonOrO process is lower than traditional technology.

For industrial applications, CarbonOrO targets energy use of 2.4 GJ/ton CO_2, significantly below the current industry (MEA) benchmark of 3.6 GJ/ton CO_2. In addition, the CarbonOrO solvent shows (in laboratory testing), less thermal and oxidative degradation than commercial solvents.

Offsets with hydrogen

Another of the projects that recently was awarded funding from DOE is the University of Kentucky dual-solvent system. In June of this year, researchers at the University of Kentucky (Lexington; www.uky.edu) received $2.4 million to develop and demonstrate a cost-effective system to capture CO_2 and produce hydrogen at natural-gas-combined-cycle (NGCC) power plants. The team has devised a dual-loop, two-solvent CO_2-capture system that reduces CO_2 concentrations in fluegas from NGCC plants to lower than that found in the atmosphere generally, making it a net-negative-CO_2 emissions technology, co-principal investigator Kunlei Liu says (Figure 2).

The system has a primary loop using an amine as the solvent. Depending on the external electricity demand, the main loop removes 80 to 95% of CO_2 from the NGCC fluegas (which contains 4 vol.% CO_2) and regenerates the solvent thermally. Then, the system uses a potassium hydroxide (KOH) solution to remove more CO_2 in a second polishing loop that brings the overall CO_2 capture to greater than 99%, Liu says. Because KOH cannot be regenerated thermally, the researchers developed an electrochemical system that generates pure H_2 while regenerating a portion of the capture solvent. H_2 production partially offsets the cost of the process.

The researchers are retrofitting the dual-solvent system on an existing 0.1-MW bench-scale facility using natural-gas-derived fluegas.

Water-lean solvents

Other companies are advancing CO_2 capture solutions that evolve from the traditional approaches by exploring water lean or non-aqueous amines. ION Clean Energy (Boulder, Colo.) is commercializing proprietary liquid absorbent and process technologies which are more effective and cost-efficient than current commercial solutions.

While ION's solvent technologies are applicable to several applications, ICE-31 (its newest), is especially well suited for natural gas combined cycles (NGCC) and natural gas boilers because it is extremely stable in oxygen-rich environments and can adapt and ramp up with commercial dispatch of power stations, the company says. In an environment where every ton of CO_2 captured is critical for capture economics, these key performance characteristics will drive CO_2 emissions even lower for load-following facilities without impacting their dispatch rate.

ION has tested and proven its solvents at the National Carbon Capture Center in Alabama and the CO_2 Technology Centre Mongstad in Norway, the world's largest and most advanced CO_2 capture test facility.

Most recently, ION has been the technology of choice for DOE-funded commercial front-end engineering design (FEED) studies for CO_2 capture systems at Tampa Electric Company's Polk Power

FIGURE 3. Engineers tested non-aqueous solvents for carbon capture at Technology Centre Mongstad in Norway

Station and Calpine's Delta Energy Center. Additionally, ION's commercial pilot at Calpine's Los Medanos Energy Center will be operational in early 2023. There, ICE-31's long-term performance will be empirically demonstrated on a commercially dispatched NGCC, sponsored by DOE-NETL and Calpine.

ION has also explored improved gas-liquid contacting devices with its patent-pending Modular Adaptive Packing (MAP) technology. ION has leveraged the power of 3D printing to create optimal contacting devices that have been successfully benchmark-tested against the best commercially available optimized packing designs. 3D printing gives ION's engineers the ability to completely reimagine the structure and design of G/L contacting devices to optimize cooling, mass transfer, liquid holdup, and pressure drop, ION says.

Non-aqueous CO_2-selective solvents are also the focus of another project recently garnering DOE support. The project stems from research by RTI International (Research Triangle Park, N.C.; www.rti.org), and involves a host of commercial and academic partners.

RTI's non-aqueous solvents (NAS) are optimized mixtures of hydrophobic amines, which capture CO_2 as amine carbamates, and hydrophobic diluents. NAS, such as the ones developed by RTI, offer several significant advantages that lower the cost of CO_2 capture. The key advantage is the lower parasitic energy penalty, explains Vijay Gupta, a chemical engineer at RTI. "NAS does not rely on the need to generate water vapor in the solvent for CO_2 stripping in the regenerator," Gupta says. "This de-coupling of the solvent regeneration from the boiling point of water allows the solvent to be regenerated at lower temperatures, allowing for use of lower-quality steam, leading to an increase in plant efficiency." The specific reboiler duty for NAS is 35-40% lower than that of 30 wt.% MEA, a leading aqueous solvent used in CO_2 capture, Gupta adds.

In addition, NAS allows regeneration of CO_2 at elevated pressures (4.2 bars) with minimal increase in regeneration energy. This lowers cost and power consumption for CO_2 compression, Gupta says.

RTI is engaged in several projects testing different variations on its solvents. A large-scale testing and demonstration project for the use of NAS in a 12-MW CO_2-capture plant is currently wrapping up at Technology Centre Mongstad. Data from the testing will be used to finalize the process setup and conduct a techno-economic assessment of the technology. Two other ongoing projects are looking at process intensification of NAS for cement and NGCC plants.

'Amine-free' solvents

Meanwhile, the company C-Capture Ltd. (Leeds, U.K.; www.c-capture.co.uk) is exploring solvent-based CO_2 capture that doesn't involve amines. The company was spun out of research by Chris Rayner at the University of Leeds to capture CO_2 from biogas and landfill gas. The company has developed an organic solvent for CO_2 capture that Rayner calls "amine-free." Although the company won't divulge the structure of the proprietary solvent, it is based on fundamentally different chemistry than that found in amine solvent systems, C-Capture says. It is capable of significantly lowering the energy requirements for releasing the CO_2 and regenerating the solvent compared to amine-based solvents.

The C-Capture process reduces the energy required for CO_2 removal by up to 90% when treating biogas, according to Rayner. Along with the solvent, Rayner and the C-Capture team have subsequently re-engineered the process equipment around it to maintain mild temperatures and pressures as a way to avoid high costs for equipment.

The company is moving the technology forward on several fronts. It has built a small pilot plant and a larger (1 ton of CO_2 per day) demonstration plant to develop the technology. C-Capture has worked with the Drax Power generation facility in the U.K. on CO_2 capture, and in July 2022, announced a partnership with the Bioenergy Infrastructure Group to provide carbon capture for the Ince Bioenergy Power facility, a biomass waste gasification facility in the U.K.

Linde, BASF and Mitsubishi Heavy Industries are among the others exploring improved solvents for CO_2 capture. But while efforts to lower the costs of solvent-based CO_2 capture will continue to be a main focus for CCUS, other approaches are also gaining momentum and support.

Cryogenic carbon capture

Another in the recent raft of funding awards from the DOE went to conduct a FEED study to retrofit an iron-making plant with CryoCap FG, an Air Liquide CO_2-capture technology based on cryogenic separation. Cryocap combines pressure-swing adsorption capabilities with cryogenic refrigeration technologies to achieve high CO_2-capture rates with high CO_2 purity, according to project leaders. Cryocap FG has been piloted at facilities in France and Denmark.

Earlier this year, Air Liquide signed a memorandum of understanding with Lhoist to apply a CryoCap system to Lhoist's lime production facility in Rety, France.

Membranes

Several companies are developing CO_2 capture with membranes rather than with sorbent materials. An example of this comes from Membrane Technology and Research Inc. (Newark, Calif.; www.mtrinc.com), which has developed polymeric CO_2-capture membranes, known as the Polaris class. The company says its membranes offer the highest combi-

nation of CO_2 permeance and CO_2/N_2 selectivity of any commercial polymeric membrane. The membranes are combined with a novel two-step process design (developed by MTR) that uses incoming combustion air to sweep membranes and recycle CO_2 to the combustion process. The benefits of this two-step membrane design include an increased CO_2 concentration to the membrane capture step and a reduction in the fraction of CO_2 removal required by the capture step, the company says. MTR design calculations estimate that this membrane process can capture CO_2 at a cost of below $40/ton under partial capture conditions.

The membranes are being tested in large-scale pilot tests designed to assess the cost-effectiveness of membrane-based CO_2 capture compared to solvent-based capture. One project, at the Wyoming Integrated Test Center in Gillette, Wyo. will capture 150 tons of CO_2 per day.

Novel approaches

While the solvent-based CO_2-capture systems are overall the most developed, several other CO_2-capture technologies have gained significant interest and investment. The following describe some examples.

Molten salts. Mantel (Boston, Mass.; www.mantelcapture.com) recently received seed funding for its CO_2-capture technology, which is based on molten borate salts. The borate salts are in the liquid phase at high temperatures (~600ºC), such as those found in industrial heating, cement, steel and hydrogen production applications. In the capture phase, CO_2 is absorbed into the liquid salts, generating heat that can be recovered as high-quality heat. This heat can drive steam production. The approach can reduce energy losses by more than 60%, and overall costs by half, says Cameron Halliday, co-founder and CEO of Mantel. "Operating carbon capture at high temperatures offers thermodynamic advantages for energy efficiency, and since the borates are liquids at these elevated temperatures, we can also realize the advantages of liquid handling over solids," he says.

Mantel is using its new funding to continue work on building a large prototype and to accelerate design of a 50-ton/d demonstration plant to evaluate a host of questions on operating the system. Mantel envisions its solutions for hard-to-abate industries such as industrial heat, cement, steel, and hydrogen, as well as CO_2 removal from the atmosphere through pairing with biogenic sources of emissions, such as bioenergy, waste-to-energy and pulp and paper.

Nanoporous networks. Jeff Reimer, a researcher at the University of California at Berkeley and Lawrence Berkeley National Laboratory, recently published some work exploring melamine nanoporous networks (MNNs) for CO_2 capture. At the kilogram scale, Reimer and colleagues demonstrated a solid-state, polyamine-appended, cyanuric acid–stabilized MNNs that is effective,

scalable, recyclable, and capable of high-capacity CO_2 capture, the team says. According to the researchers, MNNs (synthesized from commercial melamine and paraformaldehyde) are promising for reversible CO_2 capture "owing to the intriguing advantages of their robust flake-like structures, high surface areas, tunable surface chemistries and industrial-scale capture capabilities." The project is probing the nature of the chemisorption mechanism at the atomic level to aid further the design of MNNs with high CO_2 adsorption capacity for CCUS.

Electro-swing adsorption. In April of this year, Verdox Inc. (Boston, Mass.; www.verdox.com) was awarded a $1 million milestone award from XPrize Foundation and Musk Foundation for carbon removal. Verdox has developed a system for capturing CO_2 based on electrical charge that requires much less energy than approaches using temperature or pressure differentials. The electroswing adsorption (ESA) platform is similar in principle to pressure-swing or temperature-swing adsorption, but uses 70% less energy, the company says. The ESA platform is a modular system consisting of stacks of flat electrodes that are functionalized with specially designed quinones. The capturing electrode has high affinity for CO_2, but only when charged. When a cell is charged, it can bind CO_2 in a chemically irreversible step," explains Sahag Voskian, Verdox chief technology officer. "When the cell is discharged, using a counter electrode to balance the charge and complete the electrochemistry, the affinity for CO_2 falls to zero and the CO_2 is released in a pure form." The company is now conducting field trials and plans to begin construction of a pilot plant.

Metal organic frameworks (MOFs). MOFs are viewed as possible sorbent material for CO_2. An interesting example is Nuada, a technology developed by MOF Technologies (Belfast, U.K.; www.moftechnologies.com), that operates via vacuum-swing adsorption (VSA). Nuada is a combination of a proven, mature technology (the VSA) and a novel, high-capacity MOF sorbent material, applied to point-source carbon capture. By using pressure instead of heat to release the captured CO_2, Nuada cuts energy consumption by up to 80% versus state-of-the-art amine scrubbing solutions, the company says.

Nuada is designed as a compact and modular carbon-capture plant.

Ionic liquids. Ionic liquids (ILs) are another class of materials being explored for use as a sorbent material for CO_2 capture. The company IoLiTec GmbH (Heilbronn, Germany; www.iolitec.de) is exploring various combinations of IL anions and cations for capturing CO_2 from different fluegas compositions. In general, some potential advantages of ILs for CO_2 capture include faster reaction kinetics than CO_2 absorption with MEA, higher CO_2 loading and less corrosion impact. The company is constructing a pilot plant in Greece to capture CO_2 from a coal-fired power plant. ■

Scott Jenkins

Focus on Mobile Devices

A new smartphone for hazardous areas

The new Bartec Pixavi Phone (photo) is this company's next-generation smartphone for hazardous areas in Zone 1, Div. 1. It includes technical specifications that meet the requirements for the toughest industrial environments. The intrinsically safe Android phone meets the highest requirements for explosion protection, reliability and performance. The device, which is certified for Zone 1 according to IECEx and ATEX, has a touch display protected with 2-mm-thick Gorilla glass, which is easy to read in all weather conditions and can be operated reliably even with thick safety gloves. A powerful Qualcomm Snapdragon 660 processor Octa-Core 2.2 GHz ensures maximum network reliability. The Qualcomm quick charge with a magnetic charging connection ensures short-term operational capability. The Android 11 operating system is state-of-the-art and self-explanatory for experienced users. The device has a 12.2 megapixel rear camera and an 8 megapixel front camera. The camera also features phase-detection autofocus, greatly improved color reproduction and low-light enhancement for better recording in (low-light) industrial environments. — *Bartec GmbH, Bad Mergentheim, Germany*
www.bartec.de

This tablet has more power, more screen

The new series of intrinsically safe Tab-Ex 03 tablets (photo) combines high performance and maximum ease of use in a lightweight and rugged design. Based on the Samsung Galaxy Tab Active3, the Tab-Ex 03 comes with the Android 12 operating system. Users benefit from more RAM and external storage than previous models. The Enterprise Edition from Samsung Knox ensures high data and device security. The touchscreen of the handy tablet is very easy to operate while wearing gloves — an especially important consideration given the harsh ambient conditions in the process industry. The integrated Google ARCore makes the tablet suitable for digital applications in Industry 4.0, such as augmented reality. An individually programmable button enables quick and effective alarm notification, emergency calls, or push-to-talk (PTT) for maximum employee safety at all times. — *Ecom Instruments GmbH, Assamstadt, Germany*
www.ecom-ex.com

A smartwatch for hazardous areas

The intrinsically safe industrial smartwatch IS-SW1.1 (photo) is said to be the world's first ATEY/IECEx certified industrial smartwatch for zone 1/21. The smartwatch displays all important messages, hazard messages and measured values directly on the user's wrist — "hands free." Because the smartphone no longer has to be picked up to read short messages, this feature represents a decisive contribution to employee safety. Furthermore, in an emergency situation, it is possible to make an emergency call directly via the SOS button of the smartwatch on the wrist (connected to the emergency app of the smartphone) — the employee in distress can be located via GPS. The monitoring of vital functions like pulse and oxygen saturation additionally complement the safety concept. Coupled with a push-to-talk-enabled smartphone, users can employ the smartwatch as a remote PTT button. The RFID chip integrated in the smartwatch can not only read various RFID tags, but also emulate different contactless chip cards. — *i.safe Mobile GmbH, Lauda-Königshofen, Germany*
www.isafe-mobile.com

An improved cloud-hosted industrial control platform

This company has improved the scalability, data protection and threat intelligence of its Zedi Cloud SCADA (supervisory control and data acquisition) software-as-a-service control platform (photo) by moving it to the Microsoft Azure cloud platform. The more robust cloud host enables

Bartec

Ecom Instruments

i.safe Mobile

Emerson

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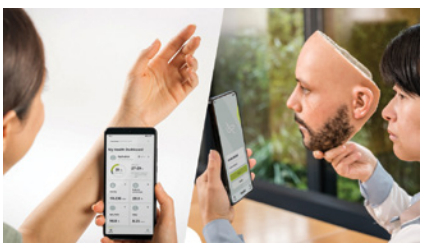
ProComSol



trinamiX Sensing

users to securely scale their SCADA systems quickly and easily to achieve environmental, social, and governance (ESG) commitments, better safeguard critical business assets and empower users to adapt their operations to changing requirements while mitigating risks and operational costs. The Zedi Cloud SCADA platform uses advanced automation and software, including proven machine-learning algorithms and artificial intelligence to build predictive models that lead to autonomous operations over time, helping support sustainability efforts in oil and gas, water and wastewater and other data-intensive industries. Critical data from those predictive models can then be stored in an operation's data historian to more easily track and trend performance and emissions and demonstrate compliance to regulators. — *Emerson, Austin, Tex.*
www.emerson.com

Expanded Microsoft Azure Machine-Learning support

Last November, this company introduced additional integration support for Microsoft Azure machine learning (ML). This new add-on enables process manufacturing organizations to deploy ML models from Azure Machine Learning as add-ons in Seeq Workbench. The result is ML algorithms and innovations developed by information technology (IT) departments can be operationalized so frontline operation technology (OT) employees can enhance their decision-making and improve production, sustainability indicators and business outcomes (photo). With the new Azure ML integration, data science teams can develop models using Azure Machine Learning Studio and then publish them using the Seeq Azure Add-ons feature. Using Seeq Workbench, frontline employees with domain expertise can easily access these models, validate them by overlaying near real-time operational data with the model results, and provide feedback to the data science team. This enables an iterative set of interactions between IT and OT employees, accelerating time to insight for both groups, while creating the continuous improvement loop necessary to sustain the full lifecycle of machine learning operations. — *Seeq Corp., Seattle, Wash.*
www.seeq.com

Convert your smartphone into a field-device communicator

Last July, this company released its new Android-based Smart Device Communicator Software for Foundation Fieldbus (FF). The software uses the Device Description (DD) for the connected FF device, so the user has full access to every parameter and method. DevComFF.Droid offers an alternative to the traditional high-cost FF Communicators, says the company. With an FF communicator that can fit in a user's pocket, utilizing a modern, application interface, the user has quick and easy access to the FF instrument data (photo). The Android App (DevComFF.Droid), in combination with the Softing mobiLink multi-protocol communicator, is a full-functioned FF communicator. The entire DD Library for FF devices from the FieldComm Group is included. New DDs can be added very easily by the user. A FF communicator that uses DDs can perform full configurations of valves, multivariable devices and complex devices, such as radar level meters and Coriolis flowmeters. — *ProComSol, Ltd., Lakewood, Ohio*
www.procomsol.com

Highly secure face authentication

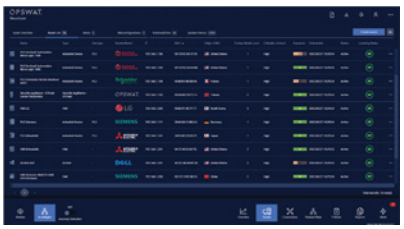
Last August, this company introduced an all-in-one, easy-to-integrate face-authentication solution in collaboration with Qualcomm Technologies, Inc. The face authentication is powered by Qualcomm Trusted Execution Environment and this company's unique algorithms to raise the protection of users' personal data. Optimized for use on Snapdragon mobile platforms, this next-generation solution has been certified in accordance with highest biometric security requirements. Face Authentication combines regular 2D face detection and recognition with the company's liveness check based on skin detection. The solution fulfills the highest biometric security requirements defined by the International Internet Finance Authentication Alliance, the FIDO Alliance and Android. It has thus been approved for Android integration and for use in digital payment processes with particularly high security demands. — *trinamiX Sensing GmbH, Ludwigshafen, Germany*
trinamaxsensing.com ■

Gerald Ondrey

New Products

A cybersecurity platform with neural-network capabilities

Neuralyzer (photo) is a new cybersecurity product that enables operational technology (OT) personnel to protect their critical environments and supply chain through asset discovery, inventory management, network visibility and vulnerability and risk management. With its intuitive OT interface, Neuralyzer goes from easy out-of-the-box installation to providing visibility into OT networks and threats in under 5 min, says the company. All of these capabilities are powered by neural-network-based machine-learning technology. Industrial and OT teams are challenged with finding cybersecurity solutions that offer complete asset visibility and inventory with little to no impact on OT networks and devices. Designed with these challenges in mind, Neuralyzer is a purpose-built cybersecurity solution that analyzes OT networks, assets and protocols. By gaining visibility into OT assets and network activity, organizations can take the first step in building a mature cybersecurity program. In doing so, Neuralyzer also allows them to manage risks to OT assets through anomaly detection, to prevent insider threats, to meet compliance requirements and to maintain proper network architecture and segmentation. — *Opswat, Inc., Tampa, Fla.*
www.opswat.com



Opswat

This strainer removes solids from without filters, bags or elements

This company's self-cleaning filters (photo) remove oversized particles from process or wastewater flows of up to 2,500 gal/min without filter elements or bags. Removing particulate matter enhances the quality of products, such as oil-based or latex paints, solvent-based or waterborne stains, high-value automotive coatings, food and beverage products and more. Various models are available for a wide range of continuous process flows. Wedgewire or perforated screens of various openings are available and interchangeable, allowing one strainer to be used for multiple applications. With no bags or elements to dispose of, this unique technology allows users to meet their plant sustainability goals. Product to be filtered enters the strainer through the inlet, with filtration occurring from the outside in. Screened particulate matter accumulates within the canister and is purged through the bottom drain as needed. Purged particles are piped away for disposal, recycling or re-use. These strainers operate continuously as a sealed device, so product stays within the piping and out of the atmosphere, which is especially important for fast-curing products like highway striping paint. The strainers are suitable for aseptic operations and work well as pre-filters upstream of membranes, centrifuges and other fine-filter media. — *Spencer Strainer System, Jeffersonville, Ind.*
www.spencerstrainer.com


Spencer STrainer System

A new line of industrial control valves

The Series 2900 industrial control valves (photo) are suitable for food and beverage, packaged water heaters, pharmaceutical and general service applications, as well as wastewater applications with moderate pressure drops and temperatures from –20 to 400ºF. The Series 2900 features rugged cast-iron body construction and is available in a variety of trim materials, including bronze, 300 stainless steel, 17-4pH stainless steel and Alloy 6 (cobalt-chromium-tungsten). Available valve body styles include two-way single-seat unbalanced, two-way cylinder-balanced, two-way double-seat balanced, three-way mixing, and three-way diverting. The equal percentage and linear plugs in the two-way valves and linear plugs in the three-way valves provide modulating control of a wide variety of fluids. — *Warren Controls, Inc., Bethlehem, Pa.*
www.warrencontrols.com


Warren Controls

Integrate safety and ergonomics in these ribbon blenders

Designed to minimize risk and maximize productivity, this company's ribbon blenders (photo) meet OSHA standards with safety shaft guards (no external moving parts) and limit switches that prevent operation of the agitator when any cover or manway is open. In addition, safety


Charles Ross & Son

grating can be installed on dedicated charge ports or across the entire blender opening for extra protection and to make it easier for operators to dump bags of dry raw material into the blender. The optional safety grating is highly customizable to provide a tailored solution to the operator's needs. For example, a 5-ft^3 blender (photo) features a special three-piece grate designed with an angled and pitched profile in lieu of flat surfaces. This provides a more rigid structure and more open area in the grating to improve the rate of loading. Powders are less likely to accumulate on the pitched surfaces, reducing the amount of sweeping required by the operator. All three sections of the grating have position sensors that interlock with the control panel, ensuring operator safety while running. — *Charles Ross & Son Company, Hauppauge, N.Y.*
www.mixers.com

A new line of chemical-resistant luminaires launched at Gastech

Launched at Gastech 2022 (Sept. 5–8; Milan, Italy), the Strongex G2 product line of luminaires (photo) is available with options for Ex Zone 1 or Zone 2 installation for applications across the oil-and-gas, chemical, petrochemical and energy sectors. According to the company, the longevity (estimated 100,000-h lifetime) of these products means they require very little maintenance and their low energy consumption and recyclable design promote sustainability.

Zalux

The G2 model incorporates an openable port to enable access for maintenance, easy change of the emergency battery, increased flexibility for installation and the ability to replace internal components to further extend life. A wireless control version is also available for the Ex Zone 2 model. A plastic housing protects the luminaire from extreme weather conditions, including corrosive, salty environments, and it provides high resistance to chemicals. The unit has no external aluminum parts, further promoting its resistance to corrosion, and can work in a wide temperature range. Its profile incorporates a heatsink with fins that helps improve heat dissipation — *Zalux, S.A., Zaragoza, Spain*
www.zalux.com

First cell-culture system made from a plant-based material

Green Elephant Biotech

CellScrew is a patented cell-cultivation system for biotechnology laboratories, which is constructed fully of plant-based materials — a first for the industry. At launch, there are two different versions that differ in the size of the growth surface: the CS10k with over 10,000 cm^2 surface area and the CS6k with over 6,000 cm^2. There are significant efficiency advantages and a reduced CO_2 footprint for users when using this novel cell-culture vessel compared to existing market solutions. Due to the large growth surface and easy handling of the CellScrew, personnel requirements and production space are reduced. At the same time, the user can save around 90% CO_2 emissions compared to conventional multi-tray stacking systems, says the manufacturer. — *Green Elephant Biotech GmbH, Giessen, Germany*
www.greenelephantbiotech.com

A one-stop shop for combustion maintenance

Ametek

This company is introducing several new combustion maintenance kits (photo) for its WDG-V, WDG-IV and WDG-HPII analyzers. Users can purchase everything they need to maintain and service their combustion analyzers in a ready-made kit, using only one part number. Assembled for specific analyzers, these kits take the guesswork out of what parts are needed for comprehensive service and maintenance. Offering these standard maintenance items in a kit format makes it easy and economical for users to order what they need to ensure their combustion analyzer is being maintained properly, says the company. — *Ametek Process Instruments, Pittsburgh, Pa.*
www.ametekpi.com

Mary Page Bailey

For details visit adlinks.chemengonline.com/82586-10

Lifecycle Cost Analysis Basics

Department Editor: Scott Jenkins

When evaluating capital projects in the chemical process industries (CPI), there are many scenarios in which there are important differences between the alternatives in terms of capital, operations and maintenance and decommissioning costs. In these cases, decisions must be made based not solely on the initial cost of an investment, but rather the investment throughout its entire useful life. Lifecycle cost analysis (LCCA) is a tool that can be used to aid decision-making in these cases. This one-page reference provides a brief review of the basic concepts of the LCCA methodology.

LCCA basics

LCCA aims to compare different capital-project alternatives on a common basis: total levelized cost, which sums initial and future project costs, adjusted to take into consideration the time value of money. This method can be applied to chemical process facilities to analyze either the entire process, sections of the process, or its unit operations individually.

Several factors are taken into consideration when developing an LCCA, including the following: quantifying the present value of initial costs, operating costs, maintenance and repair costs, disposal and replacement costs, residual value and any benefits associated with each alternative. A general formula for LCC, along with the definitions for its constituent terms terms, can be found in the shaded box.

$$LCC = I + PV_O + PV_{M\&R} + PV_{D\&R} + PV_{RV} - PV_B$$

Where:
LCC = Lifecycle cost
I = Initial cost
PV_O = Present value of operation costs
$PV_{M\&R}$ = Present value of maintenance and repair costs
$PV_{D\&R}$ = Present value of disposal and replacement costs
PV_{RV} = Present value of residual value
PV_B = Present value of benefits

Components of LCC

The components of the LCC equation are further explained below:

Present value. Present value is defined as the time-equivalent value of all cashflows from the start of the project. As the general cost of the project is affected by costs incurred at project start (or the base year), and future costs (any year after the start of the project) these expenses have to be levelized. Future costs are any costs incurred at any time between year one and the study period. They include recurring and one-time costs, affected by the discount rate.

Initial cost. The initial cost includes all capital investments to be made until the project is operational. This includes direct costs, such as equipment, materials, buildings and construction work, as well as indirect costs, such as lease, studies, permits, engineering, project management, taxes and overhead.

Operation cost. Operation costs include all the annual costs required to run the facility, excluding maintenance and repair costs. These include raw materials, utilities (water, electricity, gas and so on), operational labor and services, and indirect costs (such as lease, insurance, security, royalties, overhead).

Maintenance and repair cost. Maintenance and repair costs deal with the upkeep of the project itself and take into consideration that some of these costs can be annual or scheduled at several-year intervals into the future. Mechanical, instrumentation and electrical engineers may provide information regarding the maintenance requirements and frequency of the equipment involved in the project, while civil engineers may provide information about maintenance requirements for building, foundation and structural components; cost engineers then need to estimate rates and work hours for the required maintenance tasks. There is also a risk factor to account for non-scheduled repairs that depends on failure rates of pieces of equipment.

Downtime costs (for example, loss of production, penalties and so on) due to maintenance and repairs may also be considered, if found to be significantly different between the evaluated alternatives.

Disposal and replacement costs. Disposal costs deal with the removal of existing structures or nature on site along with the transportation of wastes generated by construction or demolition (debris, residues and so on). More important, however, are the replacement costs. Every component of a project has a useful life, and the replacement costs are generated by removing and replacing components of the project that have completed their useful lives.

Residual value. The residual value includes costs associated with the project after the study period is over. These values may be positive, negative, or zero. If the values are positive, it means that there are disposal costs attached to the end of the project (for instance, remediation costs), whereas negative values mean there is value linked to the facility at the end of the study period (for example, the plant has a useful life that exceeds the study period) and a zero value indicates no value associated at the end of the study.

Benefits. Benefits include any other value gained by the project throughout the project life. Only benefits that can be transduced into monetary value can be included in the LCCA. For instance, the value of emissions-reduction certificates or tax incentives received from implementing one design alternative would be taken into consideration. ■

Editor's note: This month's "Facts at your Fingertips" column was adapted from the following article: Giardinella, S., Baumeister, Z. and Baumeister, A. Using Lifecycle Cost Analysis for Best Project Value, *Chem. Eng.*, December 1, 2020, pp. 32–39.

Lessons Learned in the Classroom: Tower Pressure and Capacity

Henry Kister shares lessons learned from troubleshooting distillation towers

In my courses, I discuss the effect of column operating pressure on flooding and capacity. There are two counteracting effects:

1. First, as the pressure is raised, vapor density increases, which lowers vapor velocities, and as long as one deals with a vapor flood, increases capacity, the increase being very roughly inversely proportional to the square root of the pressures ratio.
2. Second, as pressure is raised, relative volatility for most systems diminishes, so one needs to raise reflux and boilup to keep the products within specification, making up for the lower volatility. This counters the vapor density effect.

The volatility effect increases in importance at higher pressures and for low-volatility systems. Additional effects are related to the thermal state of the feed: higher pressure suppresses feed vaporization, shifting hydraulic loads from the top section to the bottom, and the converse occurs upon lowering the pressure. Generally, assuming no major feed vaporization effects, the vapor density effects dominate at pressures below 50 psia, while the volatility effects dominate above 150 psia, with a grey area in between. Further, most floods above 150 psia are downcomer chokes, which are primarily liquid floods. These are only slightly affected by vapor density, so the volatility effect is not countered and dominates. At high-pressure distillation, lowering the pressure usually gives significantly higher capacity.

In one of my courses, early one afternoon, a delegate showed a lot of interest in these statements. He started firing questions at me, one after the other. I answered them to the best of my ability. After his fifth question, he quickly got up and left the room. He did not return.

I was restless that evening, thinking that I must have said something that offended him. My mind went through his questions and my answers, to the best of my memory, but I could not identify the offensive reply. I convinced myself that I said something that I did not intend nor remembered — or maybe my tone was too harsh.

I was relieved to see this gentleman turn up to the class the next morning. I immediately walked up to him and apologized. "I am sorry I offended you, sir. I surely did not mean to, but obviously said something inappropriate for which I sincerely apologize."

"What the heck are you talking about?" He replied.

"I tried to answer your questions to the best of my ability, but I probably used some wrong words or tone, because I saw you storm out of the room."

He laughed. "Quite the opposite. You did us a big favor. Our entire plant has been bottlenecked for years by a tower operating at 170 psig. We were pushing the operators to raise the pressure as high as possible, just enough to keep a comfortable margin from the relief-valve setting." He continued "Yesterday, you stood here and told us that we should be going the other way. None of us expected this. I needed to make sure that I got it right and fully understood. That is why I fired all those questions. Your replies convinced me that lowering the pressure is the way to go, so I rushed to our plant, and requested the operators to lower the pressure. We are now running at 130 psig, and have achieved a record unit throughput, 10% more than before. We thank you for this. Just the production increase already paid for your trip. The rest is gravy."

This was a relief to hear, and a very precious moment.

The takeaway: There can be some anxious moments before the success of a treatment is realized. ■

Edited by Dorothy Lozowski

About the Tower Doctor

"The Tower Doctor" is the honorary title bestowed upon the author of this article in 2002 by Richard Darton, professor of Engineering at Oxford University and chair of the European Distillation Network. "When a tower is not well," says Darton, "people call Henry to diagnose the illness and find a remedy. He arrives with his doctor's bag, examines the patient-tower, measures its temperature and pulse, gets radiography to get an inside look. Then comes his diagnosis and cure. Towers treated by Henry mostly get better very quickly." Being son to two medical doctors who were blessed with phenomenal diagnosis ability, the author aspired to live up to this special honorary title. Like with medical doctors, some illnesses were a struggle to diagnose, others were easier. All were exciting. This column will reminisce through some of the more entertaining cases. They may not have seemed entertaining at the time, but looking back at them, they leave unforgettable memories and raise a smile or two. One great aspect of being a tower doctor, one gets to work with and learn from some of the greatest engineers and operators that contributed so much to the chemical industry. We hope that this column can pass some of the fun, excitement and lessons learned to future troubleshooters and tower doctors.

Author

Henry Z. Kister is a senior fellow and the director of fractionation technology at Fluor Corp. (3 Polaris Way, Aliso Viejo, CA; Phone: 949-349-4679; Email: henry.kister@fluor.com). He has over 35 years of experience in design, troubleshooting, revamping, field consulting, control and startup of fractionation processes and equipment. Kister is the author of three books, the distillation equipment chapter in Perry's Handbook, and over 130 articles, and has taught the IChemE-sponsored "Practical Distillation Technology" course more than 530 times in 26 countries. A recipient of several awards, Kister obtained his B.E. and M.E. degrees from the University of New South Wales in Australia. He is a member of the NAE, a Fellow of IChemE and AIChE, and serves on the FRI Technical Advisory and Design Practices.

Milling in the Pharmaceutical Industry

Milling active ingredients combines equipment selection, material characterization, and process characterization, with the aim of improving and controlling the properties of the solid crystalline drug substance. These topics are discussed here

Ivan Lee and Eric Sirota
Merck & Co., Inc.
Aaron Moment
Columbia University

Milling is a common technique used for the reduction and control of particle-size distribution (PSD) for active pharmaceutical ingredients (APIs), many of which are crystalline solids. Regulatory expectations require APIs of high purity, and consistent well understood physical properties [*1*]. Particle characteristics of APIs, such as solubility and surface area, and important powder characteristics, such as flowability and compressibility, impact bioavailability (BA) parameters when formulated into drug products (DPs), such as tablets, capsules, suspensions and inhalation products [*2, 3*].

Overview of milling

Mills are useful tools to generate API particle properties with desired and consistent properties, through size reduction and surface modification mechanisms. The use of mills in the pharmaceutical industry remains prevalent, due to their modular nature, predictable performance and wide range of equipment availability. The choice of mill for a specific application is dependent on the performance capabilities relative to the properties of the feed material, as well as any constraints particular to the mill that is being considered for the function. The comparatively low-volume nature of pharmaceutical products means there are fewer concerns about energy utilization in milling than in mining and commodity chemicals.

Particles can be conveniently characterized by a characteristic size, L (m), of the particle [*4*]. The distribution of size for a population of particles is then communicated through the normalized frequency distribution $f(L)$, and cumulative distribution $F(L)$, often measured by a light-scattering technique [*4*]. The feed and the milled product are characterized in terms of these, and often specifications are placed on the product cumulative distribution $F(L)$, which is the fraction of particles less than or equal to L. Although statistics are used extensively to characterize size distributions and their specifications, there is no adequate substitute for imaging particles, because their shapes and surfaces are not completely described by statistical metrics.

Milling results in particle size reduction, the creation of new surface, and surface modifications — roughness, for example. This transformation is achieved by the comminution mechanism, whereby the solid particles are fractured by mechanical force delivered to particles, achieved in a myriad of ways depending on the mill type. Surfaces of milled products are modified through the fracture mechanism and by abrasion.

Broadly, mills can be separated into wet and dry mills, and these two categories are each further subdivided by how comminution is achieved, such as rotor-stator mills, jet mills, pin mills, hammer mills, media (ball) mills and cavitation mills. Wet mills use liquid as their working fluid, whereas dry mills use gas.

Common mill types and their characteristics are provided in Table 1. Each type of mill is characterized by an energy input mechanism and a particle-breakage mechanism. As a rough guide, the mill type is selected against the product size range when milling solids. In turn, the size range of the product is informed by formulation development, modeling, and the Biopharmaceutics Classification System (BCS) class of the compound. Scaling up the milling operations is specific to each type of mill, and revolves around the normalized energy input to the particles. Consistency of mill supplier is helpful in maintaining control of processing at various stages of development.

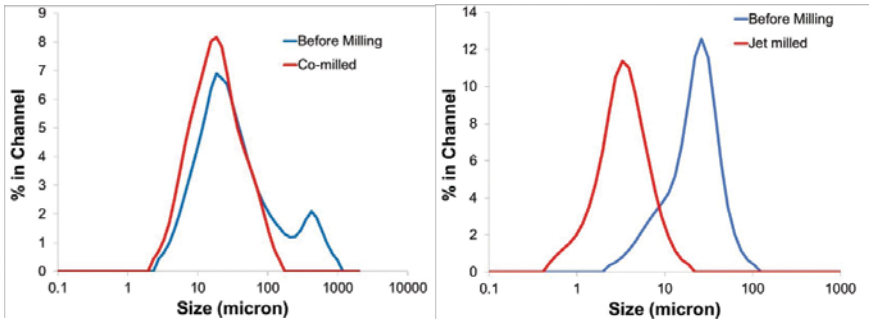
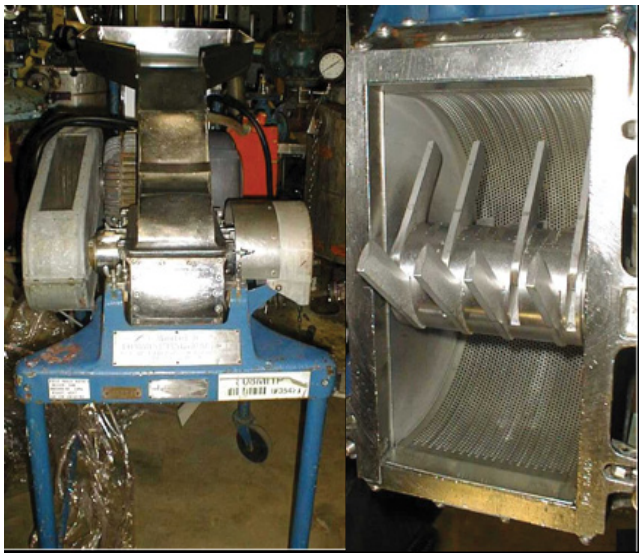


FIGURE 1. Shown here is the particle-size distribution before and after co-milling (left) and before and after jet milling (right)



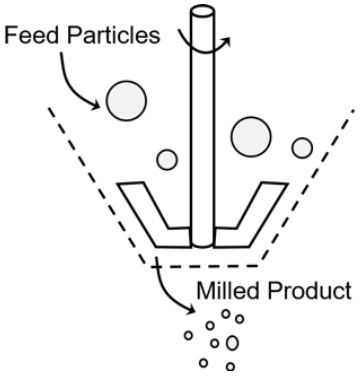


FIGURE 2. The photos show a hammer mill motor (left) and a a cutaway showing the hammer mill screen and hammers (middle). The comill schematic (right) shows the rotating element, the screen, the feed particles and the milled product

What size range is needed?

The required size range for a pharmaceutical compound formulated as a solid is arrived at through experimental human and animal tests, along with modeling of the absorption behavior of the formulation. The BCS classification system provides a guideline for solid oral products through their solubility and permeability [*8*]. BCS Class III products, having high solubility and low permeability, are dissolution-limited in their absorption, and hence, can be very sensitive to particle size distribution. BCS Class I products may not require as tight control of distribution due to their rapid uptake. BCS Class II and IV may require additional formulation work to improve absorption through additives. Inhalation products will have extreme requirements based on the physics of deposition in the lung [*9*], with specifications of 1–2 µm being common.

How milling impacts PSD

Milling changes the size distribution and is intended to provide normalization; that is, a similar size distribution of product is obtained for various size distributions of feeds. Theoretically, a milled product is predicted to have a log-normal or Weibull distribution [*10*], related to the probability of a particle fracturing and the nature of the fragment as a function of its original size. Practically speaking, this means that milling does not typically give symmetrical Gaussian distributions, and instead skewness and tails are common depending on the type of mill. Figure 1 provides examples of size distributions before and after milling for a couple of the common techniques.

Milling also impacts the shape, or morphology, of API crystals, particularly for high aspect ratio "needle" or "rod" type particles. The comminution fracture mechanism is often along the length of these crystals, effectively chopping them along the length scale into lower-aspect-ratio shapes, with consequent change in the physical attributes, such as bulk density, as well as formulation behavior, such as flow properties — in a slurry as well as in a solid DP mixture. The practical manifestations of aspect-ratio reduction include less plugging inside a syringe for an injectable drug and improved flow properties for better mixing and DP content uniformity (CU) parameters, such as RSD (relative standard deviation) for solid dosages, including inhalants or implants. Reducing aspect ratio can also lead to better compressibility/compactability for tablet formulations and achieve a higher dosage in a solid capsule without resorting to granulation methods (wet or dry) to help densify the drug product intermediate.

TABLE 1. COMMON MILL TYPES AND CHARACTERISTICS

Mill type	Wet or dry	Energy input particle breakage	Characteristic maximum velocity, m/s	Specific energy input to solids	Product size range, d_p
Jet mill	Dry	gas velocity particle-wall particle-particle	343 m/s sonic	High	1–5 µm
Media/ ball	Wet	rotational speed and media type particle-ball	Impulse impacts 2–4 m/s [5]	High	<5 µm (depends on bead size)
Pin mill	Dry	rotational speed particle-pin	37 m/s to 240 m/s [6]	Medium - high	10–20 µm
Rotor-stator	Wet	rotational speed particle-pin particle-fluid	20–50 m/s	Medium	10–40 µm
Hammer mill	Dry	rotational speed particle-hammer	14–30 m/s [7]	Medium - low	<100 µm
Comill	Dry	rotational speed and screen particle screen	8–17 m/s [7]	Medium - low	< 100 µm

Properties of crystals

While milling energy has a direct correlation to particle-size reduction, the physical properties specific to the crystalline API particles also have an important effect as well. The mechanical strength of a crystalline organic compound can now be modeled and calculated by computer models once the crystalline lattice is determined by assay methods like single-crystal X-ray diffraction (XRD). The lattice energy is sometimes presented as attachment energy, meaning the amount of energy required to pull apart adjacent crystalline planes. Additional mechanical properties, such as the Young's modulus and tensile strength, can also be estimated from the theoretical attachment energy.

Empirically, we can use a lower energy "weaker" mill, such as a rotor-stator wet mill at a lower tip speed (25 m/s) to assess and rank the relative friability of API crystalline forms in a semiquantitative manner. Running in batch mode, we can reach the steady state PSD in about 90 s for a 3-g test batch and then analyze the milled particle size. Less friable crystals only reach d_{50} (mass median diameter) particle size in the 40- to 50-µm range, while moderately

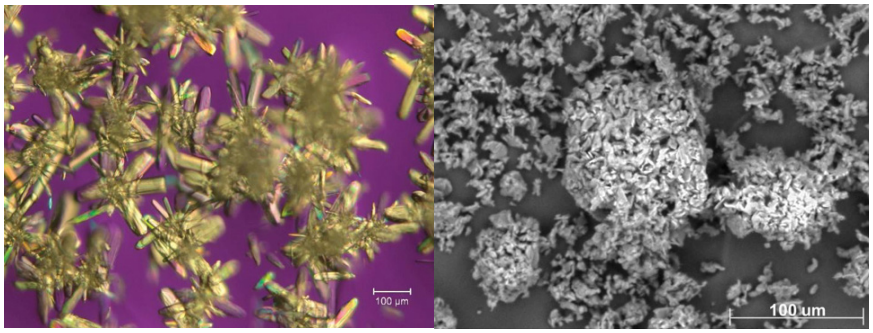


FIGURE 3. These micrographs show "starburst" (left) and spherical agglomerated crystals (right)

friable crystals are reduced to 20–30 µm and the most friable crystals can go down to 10-µm size. In addition, we have observed that when exposed to more mild milling methods, the milled PSD of stronger crystals show a dependence on the starting particle size, while for weaker and friable APIs, the milled PSD is often independent on the initial size.

The crystal shape and morphology can also have an effect on the milling performance, and here again higher-aspect-ratio particles have more unique properties. For example, needle-shaped crystals are often challenging to fracture in rotor-stator wet mills, because the long thin particles tend to follow the flow patterns of the suspension liquid and therefore result in glancing collisions that are significantly less effective at breakage, so a needle could at most be chopped once along the length axis. For dry milling, where the carrier media is gaseous, this effect is much less pronounced, and a needle may be broken into many more low-aspect-ratio particles. Crystal morphology also impacts the orientation of the particle fracture and the surface area changes from particle size reduction. Again, higher-aspect-ratio crystals, such as needles or rods, are more likely to break along the length axis, even if the attachment energy of the cleavage plane is higher than other potential cleavage planes, due to the angle of impact and mechanical moments experienced during collisions and other factors. When broken along the length axis, the increase in surface area may only be 10%, even though the particle size drops by 50%. On the other hand, breakage along any axis of a more isotropic 3D cube-shaped crystal that causes the same 50% reduction in particle size will also generate twice the number of particles and twice the surface area.

Mills for dispersion and sieving

Comills or hammer mills (Figure 2) disperse agglomerates or aggregates of crystalline APIs, instead of particle size reduction via the comminution mechanism. Aggregates are particles that are fused together from solid bridges of precipitated API out of the evaporated interstitial mother liquor or cake-wash solvents, or through a contact bridge. These aggregates/agglomerates are often formed after the filtration and drying operations, when solvent-wet particles clump together due to surface-energy effects between the crystalline solids and solvents, as well as potential exacerbating effects from mechanical agitation of the drying cake, of from compression during storage due to normal force. Smaller-sized crystals are often more liable to form aggregates or agglomerates because of their increased surface area and improved packing capabilities. Aggregate/agglomerate sizes can range from a few fine- (micron) sized particles stuck together to a 10-µm range agglomerate, up to multi-centimeter-sized granules (lumps) that are easily visible to the eye without any optical magnification. For most crystalline APIs, agglomeration is undesirable because of the inherently lower reproducibility and control over API physical properties and formulation behavior that often leads to lower content uniformity or compactability of the DP.

Comills and hammer mills can operate with significantly lower mechanical energy compared to a jet mill, resulting in dispersing of the aggregates or breaking only the weaker solid bridges connecting the agglomerate particles together [*11*]. The effect is similar to forcing the granules or agglomerates through a mesh screen, usually with no reduction in the primary particle size of the API. On the other hand, these type of degranulation "mills" usually lack sufficient mechanical energy to fracture crystalline agglomerates generated by high supersaturation-related nucleation and agglomeration-driven macrostructures, such as "starburst-" shaped agglomerates (Figure 3, left); or spherical crystals composed of submicron- to micron-scaled fine particles (Figure 3, right) — unless perhaps operated at very high tip speeds in the 100 m/s range. Higher energy jet- or pin-milling equipment will disperse all but the smaller diameter agglomerates, but sometimes will also fracture the primary particles as well, resulting in lower than desired API PSD.

The comill is essentially a screen with controlled sieve size and a rotating element that pushes the powder through the screen. The spacing of the element from the screen, the rotational rate, and the screen size are the important parameters. This type of mill is sometimes called a delumper because the primary purpose is to remove lumps and loosely bound aggregates over large size ranges.

The hammer mill (Figure 2) is a dry mill that is more unique in that it

FIGURE 4. Shown here are various rotor/stator pairs for wet mills

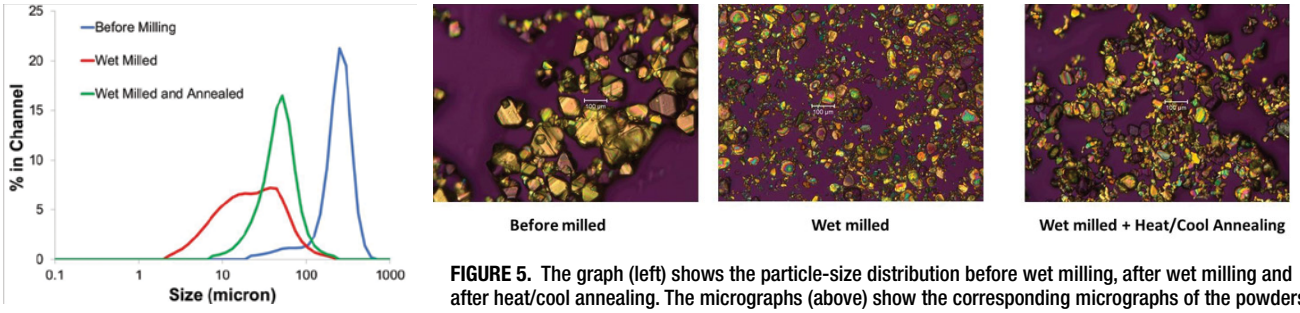


FIGURE 5. The graph (left) shows the particle-size distribution before wet milling, after wet milling and after heat/cool annealing. The micrographs (above) show the corresponding micrographs of the powders

can act to either disperse agglomerates or fracture particles (albeit usually larger sized ones) depending on the operating conditions. The "hammers" are arrays for rotating fin-like blades, with one side being a flat contact surface (the "hammer"), the opposite side a tapered sharp blade geometry. Depending on the direction of rotation, this mill can use either a blunt impact mechanism or a sharper cutting action to effect particle fracture or agglomerate dispersion. The tip speed (and consequent mechanical energy conferred from the blades to the particles) is the primary deciding factor on whether degranulation or comminution occurs.

Wet milling

Most APIs are crystallized in water or organic solvents, which are Newtonian fluids and incompressible. In wet milling, the slurry containing crystals is directly milled in a rotor-stator device prior to filtration and isolation of the product. The wet mill rotors and stators are composed of walled disks with gaps, called "slots" or "teeth," on the walls (rotor/stator pairs are shown in Figure 4). When spinning at a high tip speed, the rotor acts like a centrifugal pump, which moves the API in solvent slurry through the mill and forces flow through the narrow slots, creating transient highly turbulent eddies that constitute the mechanical energy source for particle breakage, likely due to force moments transferred from the liquid media to the particles.

Historically, rotor-stator wet mills were used to form emulsions via the shear forces attained from the high turbulence zones within the teeth/slots that the oil-water mixtures were forced through, with the droplet size determined by the tip speed and the fluid properties of the two immiscible liquids. In milling applications, force transfer occurs directly through the media to the target particles, so the mechanism of action is often shear forces due to highly turbulent flow being transferred from the liquid to the solid, which is the cause of the massive fracture events that produce the particle breakage along defects in the particles due to crack tip propagation.

Organic crystals are relatively brittle and don't possess ductile healing properties. On the other hand, the liquid viscosity can act as a lubricating layer that dampens the force in particle-particle or particle-wall collisions, making this fracture mechanism less effective. The higher viscosity of liquids also makes for much lower energy usage efficiency, since the majority is dissipated in the form of heat generated by viscous friction forces [*12*].

Rotor-stator wet mills have historically been used as emulsifiers for water-oil blends, such as for the food or cosmetic industry, but recently have been also utilized for API particle-size reduction. The term colloid mill is sometimes used for these devices and is a technology dating from the early 1900s [*13*]. In addition to terminal milling of the API slurry prior to filtration, the wet mill can also be used to normalize a seeded slurry for a co-feed or reverse addition crystallization process to indirectly control the crystallized API particle size. In addition, rotor-stator wet mills operating at high tip speeds can be used for amorphous precipitation or direct crystallization (fast mixing and potentially shear-induced nucleation effects), where the precipitated particles are often smaller in size due to the high shear environment. In these cases, the mill is used as a high-shear mixing device.

For rotor-stator wet mills, the extent of particle-size reduction can be correlated to a suitable parameter for milling intensity and to the exposure of the slurry to the mill. The simplest parameter for milling intensity is the tip speed (in m/s) at maximum diameter. Holding tip speed constant is useful when scaling up and down to maintain similar conditions. More detailed considerations include accounting for the mill geometry through slot events [*14*], shear frequency [*15*], and a cumulative normalized energy input [*16*]. Exposure to the milling event relates to details of equipment and recycling through the mill, and is managed by monitoring the process versus time either in batch or recycle mode.

Rotor-stator wet mills often generate fine particles via attrition, with consequent potential negative impact on the filtration rate, broadening of the PSD for less consistent BA performance, and formulation issues like tablets partially sticking to the presses (an elegance problem that could impact the dose if severe enough). We can add a post-milling

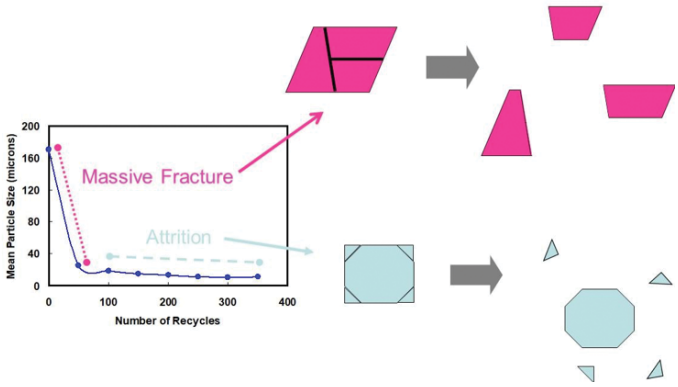


FIGURE 6. In wet milling, there are typically two different mechanisms at play, the massive-fracture regime and attribution regime, which are illustrated here

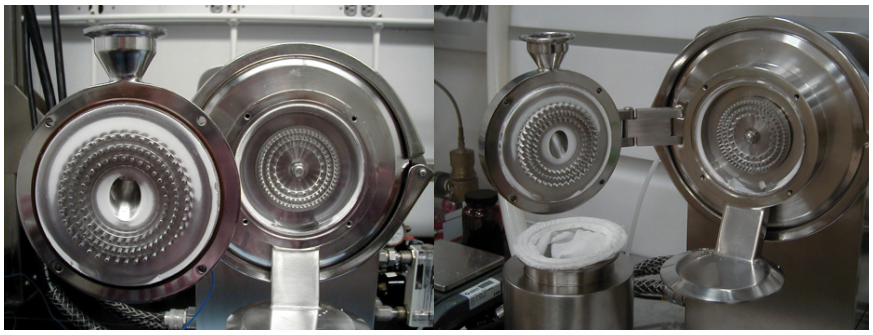


FIGURE 7. Two different views of a rotor-stator pin mill are shown here

heat/cool annealing of the API slurry, which utilizes the increased solubility of API at elevated temperature with Ostwald ripening (where smaller particles are preferentially dissolved and precipitated back out onto the remaining larger particles) to improve the PSD, by shifting the mean particle size upwards and narrowing the distribution and eliminating shoulders or other modes to create a monomodal Gaussian type PSD. Heat/cool annealing can result in more consistent PSD profiles and eliminate the troublesome fine particles (see Figure 5).

At high-tip-speed operations, the batch slurry can receive enough heat input from the wet mill to raise the exiting stream temperature significantly, followed by cooling once the batch stream returns to the feed vessel and is blended back with the bulk slurry. This results in a sort of real-time annealing effect that can sometimes eliminate fines right after formation, negating the need for a separate annealing step.

On the other hand, the temperature increase from high-tip-speed rotor-stator wet milling could cause too much annealing and partially offset the size reduction of the mill, so that the PSD does not reach the fullest possible reduction that the mill is capable of producing. Therefore, when wet milling at high tip speeds appropriate temperature control is an important consideration. Annealing can also smooth out the particle surface and "heal" defects caused by collisions or other mechanical impacts, resulting in surface areas that are significantly lower compared to dry-milled particles in the same size range and morphology.

Although the geometry and rotation of a rotor-stator wet mill imbues it with a pumping capacity akin to a centrifugal pump (has an almost linear pump curve and will "slip" instead of "dead head" and pressurize like a positive displacement pump), the inlet feed line to the mill can still be clogged if the pre-milling API particles size is too large, has high aspect ratio, high slurry concentration, poor mixing in the container vessel, or some combination thereof. One simple way to resolve potential feedline blockage by API is to install a positive-displacement pump, such as a diaphragm pump, upstream of the wet mill, to force batch slurry to flow into the mill where it can be properly digested.

Another differentiation is the recycle versus single-pass movement of the API solids through the mill. Most wet milling, whether rotor-stator or media, is conducted in recycle mode, where the batch slurry is recirculated from the holding vessel through the mill, often for multiple batch turnovers, until the PSD reaches a pseudo steady-state minimum. At this minimum, there is a very slow decrease in the size, because particle fracture has stopped (likely due to the smaller particles now lacking sufficient inertia for effective force transfer to cause massive fracture). Then, the only remaining breakage due to weaker attrition related chipping and consequent fines generation (Figure 6) for a classic two-stage particle size versus batch-turnover plot, where initial steep drop in size in the "massive fracture" regime transitions to an shallow, almost flat regime driven mostly by the "attrition" mechanism.

The reason why multiple passes are required to complete wet milling is because particle breakage is dependent on the product of number

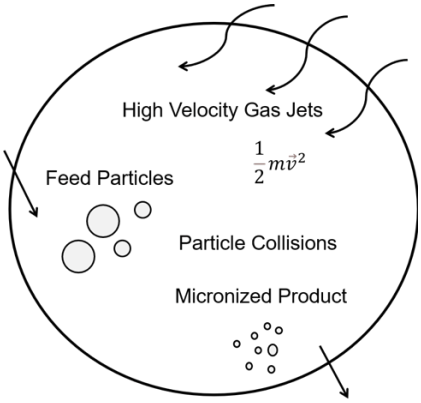


FIGURE 8. Inside a spiral jet mill chamber, feed particles are micronized by high-velocity collisions created by gas jets. The gas enters through nozzles at a pressure as high as 10 bars and with sonic velocities

of (breakage inducing) "events" and the breakage efficiency. Residence time considerations in the tank imply that recirculation is useful to ensure that all particles are exposed to a similar milling environment and time. Whether run in batch mode (in the laboratory) or a recycle mode (at scale), the general characteristics of the milling curve are retained with energy input versus particle size being a reliable method.

Other examples of wet mills with different mechanism of action are media mills, which use spherical beads made from ceramics, such as zirconia oxide, or polystyrene (PS), to reduce API particle size, often to one or two orders of magnitude smaller than the milling media. This mechanism involves a sort of grinding, polishing attrition type action, where again the dense and viscous liquid acts to lubricate the beads, as well as help to dissipate the frictional heat generated from the grinding mechanism. Cavitation mills, rarely deployed for API comminution, utilize yet another mechanism for generating mechanical energy, via dramatic pressure drop that causes cavitation. Extremely rapid evaporation generates transient gas bubbles, which then collapse violently to cause shock waves to propagate through the adjacent liquid phase to fracture the suspended particles.

As mentioned above, media mills utilize a grinding media made up of materials such as ZrO_2 (often stabilized and hardened by yttrium) or PS to reduce the API PSD significantly, similar to the performance of jet mills. However, there are some practical issues with using media mills for API processing. The beads can still shed, especially in the presence of more abrasive API compounds. For Zr-based beads, elemental analysis can detect and quantify the amount of shedding in the milled API, but for "transparent" beads, such as PS, we lack a reliable method to detect any shedding contaminants, which poses a quality and safety issue, especially if the API is going to be an injectable or inhalant. Also, the milled API still needs to be isolated via filtration, where the very small particles with high surface area often form agglomerates during drying, causing a loss of effective PSD and surface area that defeats the purpose of milling.

A possible solution is to use media mills on the DP side for a suspension-type formulation. Another possibility is testing some variation of thin-film or wiped-film evaporation to drive off the solvents, while hopefully keeping the fine particles from clumping up and aggregating in the process (often the first step into formation of harder fused agglomerates upon drying). However, the agglomeration issue and bead-shedding issue tend to make media milling less attractive of an option for API size reduction.

Dry milling

"Dry" mills operate in a gaseous environment, usually an inert gas like nitrogen being either a carrier stream for the pin mill, or also providing the mechanical energy for the particle collisions, as in the case of jet mills. In the milling conditions, these gases are at significantly lower density compared to liquids and are also compressible, so there are much less viscous dissipation and dampening forces, allowing particle collisions — with other particles or the mill walls — to become the major particle-fracture mechanism. While this allows for more efficient energy usage, the particles also absorb most of the heat generated by the collisions, which could be problematic for crystals that either have a low glass-transition temperature (T_g) (and thus could lose crystallinity or even turn amorphous), or desolvate, or convert to a different crystal form due to the temperature increase. Milling in a dry environment can also result in more static buildup on the particles, since inert gas isn't an effective conductor or carrier of electrostatic charges that are created by the mechanical energy from the numerous collisions. Although most dry mills are constructed from relatively conducting metallic materials, some residual charge on the milled API particles could make them cling to the walls or clump together and become difficult to handle or collect.

The pin mill has metal pins on both the rotor and stator (Figure 7). And while the rotor spinning at high tip speeds will also cause a vacuum draw and pumping effect that, combined with centrifugal force, transport the particles suspended in nitrogen through the array of pins, the primary mechanism of action is particle collision with the pins, along with particles being imparted with mechanical energy from the pin and subsequently colliding with another particle in its path [*17*].

In the dry mill category, jet mills utilize high-pressure gas streams to suspend and accelerate the API particles to cause particle-particle and particle-wall collisions (the latter evidenced by abrasive API crystals causing erosion and metals shedding from the product contacting internal mill surfaces) [*18*]. Although jet mill "raceways" are sometimes of different geometries (common examples are circular tracks for "spiral" mills (Figure 8); or an oval/bean shaped raceway for a "loop" mill, which, when scaled up, turns into a cylindrical tube formed into a "D" shape). Although the mill internal geometries, as well as the flow pattern and direction of the gas jets of the mill namesake differ, jet mills generally share the same mechanism of action. The particles in the jet mill continue to impact the raceway until they are small enough to traverse the path without wall collisions and then leave the mill.

The milling setup is dependent on the mill mechanism of action and the API suspension media. From an operational viewpoint, the largest discrepancy clearly lies between wet milling and dry milling. Wet milling is usually (but not always) conducted "terminally" — that is, after crystallization is complete, but in the post-crystallization API slurry (after which the milled API is usually isolated via filtration and then dried), like a con-

ventional unmilled API batch. Thus, wet milling is a separate operation, but not a separate step. Dry milling is conducted on the filtered and dried API and therefore is considered a separate and discrete step from the crystallization step. It has a distinct product loss (mostly due to fines entrainment into dust bags and physical losses to the equipment internal surfaces and charging devices like hoppers) of about 5–10%, which is a significant yield-reduction that is hard to ignore.

Dry milling is often conducted in single-pass mode regardless of mill type, even if the different mill types are divergent in milling energy. It is difficult for dry mills to set up a recycle-type loop like that for wet mills, while conducting multiple single passes is operationally burdensome. Instead, the preferred strategy is to select a higher-energy dry mill like a pin mill or jet mill when a smaller size is required.

High-energy dry milling operations are routinely screened for metal leaching into the milled product, abrasion of the mill surfaces, and crystallinity of the resulting product. It is usually desired to retain crystallinity and a reduction in crystallinity on milling is unfavorable from a product property control point of view. Wet-milling techniques usually do not have these same considerations, a practical reason for why the wet-mill can be favored.

Concluding remarks

Milling active ingredients combines equipment selection, material characterization, and process characterization, with the aim of improving and controlling the properties of the solid crystalline drug substance. The basis for mill selection and operational conditions is typically a target size range defined by the biophysical properties, or a size range defined by processing considerations (for example, content uniformity) in blending downstream (or both). Various conditions are screened including variation in feed to define conditions, followed by larger-scale trials. Particle-size distributions and mill-energy input are the key metrics. The milling techniques are well described by their working fluid, energy input mechanism, and fluid mechanics design. Rotating mills can be scaled at a crude level using the tip speed at the maximum diameter, with more refinements depending on mill specifics. Non-rotating mills are described by the specific energy input relative to the solids feed, for example of the kinetic energy of the feed gas divided by solids feedrate. ■

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Acknowledgment

All photos courtesy of Merck & Co., Inc.

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New Membrane Applications for Traditional Water-Treatment Processes

Membrane-supported processes can bring many benefits in water-treatment applications where membranes have not traditionally been used

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Reverse osmosis (RO) is the standard treatment technology for purifying water supplies for potable water applications and many industrial processes. One of four crossflow, pressure-driven membrane-separation processes, RO rejects salts, as well as low-molecular-weight dissolved organic compounds. As pressurized water flows over the membrane surface, a portion is forced through the membrane and produces purified water (permeate). This process can be described as filtration on an atomic scale.

Because of their lower cost, most RO membrane modules (elements) in use today are of the spiral-wound configuration (Figure 1). However, the close spacing of the membrane layers are susceptible to fouling by many water-borne contaminants. This, coupled with the fact that the typical spiral-wound RO membrane element cannot be backwashed, makes them susceptible to fouling of the membrane surface, which is the primary cause of failure in RO processes.

Typically defined by their pore sizes, there are three additional technologies besides RO in the suite of membrane separation processes: nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF). The use and applications of these membranes are a function of the chemical characteristics of the contaminants to be removed and the pressure requirements of each technology. This article outlines the use of newer UF and MF membrane technologies for traditional wastewater-treatment applications.

Water impurities

Although their concentrations can vary widely, the following inorganic chemicals are found in virtually all raw water supplies:

- Calcium
- Magnesium
- Sodium
- Silica
- Chloride
- Bicarbonate
- Sulfate

In addition to the above chemicals, water supplies contain various concentrations of suspended solids, such as soil, dust, clay and others, and often organic contaminants.

Groundwater sources usually have lower concentrations of suspended solids, but higher concentrations of inorganic chemicals, including relatively insoluble compounds containing iron and manganese. Various water sources may concentrate these inorganic elements due to evaporation or from reject streams from other processes. Examples include cooling towers and RO-reject (concentrate) streams.

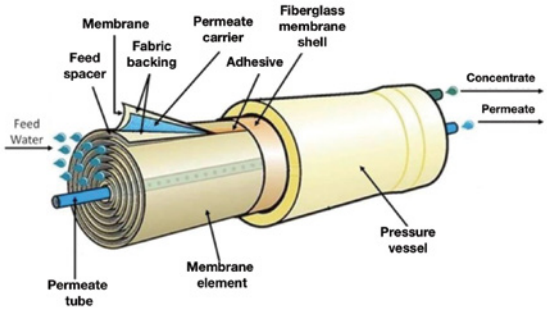

FIGURE 1. The spiral-wound configuration is the most common membrane module used in reverse-osmosis installations

Because of their relatively low solubilities, calcium, magnesium and silica present problems in many water-treatment applications. Virtually all natural water sources are subject to scaling from calcium and magnesium compounds (often referred to as hardness), and certain locations are subject to silica scaling.

The traditional process to remove chemical compounds that cause hardness is lime softening (also known as lime-soda treatment), which involves the addition of lime (calcium oxide or calcium hydroxide) and soda ash (sodium carbonate) to raise the pH to about 10.5, caus-

TABLE 1. MF PERFORMANCE MATRIX

Operating parameter	Flux	Fouling rate	Power
Increasing transmembrane pressure	Increases proportionally until the gel layer (and eventually membrane) begins to compact	Increases	Increases
Increasing crossflow velocity	Increases due to gel layer thinning	Decreases	Increases
Increasing total suspended solids	Increases flux due to the effects of membrane surface scouring	Decreases due to the thinning of the gel layer	Increases very slightly due to fluid density increase
Increasing temperature	Increases	Depends on the fouling material	Virtually no effect

FIGURE 2. A gravity settling clarifier is commonly used to remove suspended solids in many wastewater treatment plants

ing the hardness to precipitate as calcium carbonate and magnesium hydroxide. Because of the reaction time required for complete precipitation to occur (1.5–3 h), large reaction tanks are required. In addition, this process produces a high volume of precipitated calcium carbonate and magnesium hydroxide in a dilute solution (less than 20% solids) usually requiring dewatering and disposal.

The stoichiometric concentrations of the added chemicals depend on the feedwater analysis. However, the treated water will still contain some hardness, usually in the range of 50 to 85 mg/L.

Silica can be effectively removed in this process, usually by coprecipitation with magnesium. Depending on the feedwater analysis, this may require the addition of magnesium chloride and ferric chloride. In many applications, sodium hydroxide is used instead of lime. This is a more expensive chemical — however, it generates less sludge. In industrial wastewater treatment, heavy metals are traditionally treated by raising the pH to create insoluble oxide (or hydroxide) compounds, which are also removed by virtually the same clarification process as described above.

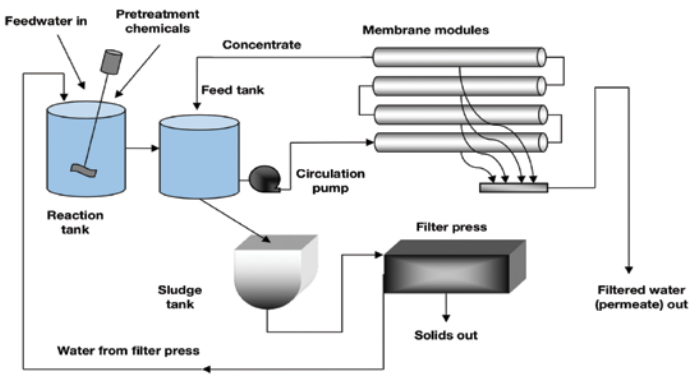

FIGURE 3. A crossflow-membrane system using MF or UF modules can achieve good separation of suspended solids from wastewater

New membrane technologies

An advanced membrane-based process is now being utilized to replace the traditional clarification and settling processes used to remove suspended solids in water-treatment processes. Normally, clarification and settling processes allow the precipitated solids to settle out by gravity. Figure 2 shows a typical gravity settling clarifier.

Conversely, in the new membrane process (Figure 3), the chemically treated solution is recirculated through a tubular MF or UF membrane designed to continuously dewater the stream, producing a filtered water stream (permeate).

The concentrate stream of the membrane is recycled back to the feed tank to increase the solids concentration to approximately 6%, at which point the stream is discharged into a sludge tank (settler), and from there into a filter press for final dewatering to a solids concentration as high as 80%. The membrane usually has a nominal pore size of 0.10 µm and the tubular elements are typically 8-mm diameter and constructed of polyvinylidene difluoride (PVDF) polymer. Figure 4 shows an end view of typical tubular membrane modules.

The mechanism of contaminant rejection is size exclusion (absolute filtration) — meaning that what is too big will not go through the membrane. Typically, the filtered material will build up a "gel" layer on the membrane surface, which may actually help to filter out smaller contaminants. The flow of the feedstream across the membrane surface (crossflow velocity) is intended to minimize this layer thickness.

FIGURE 4. Tubular membrane elements can be used in place of a gravtiy clarifier for some water treatment applications

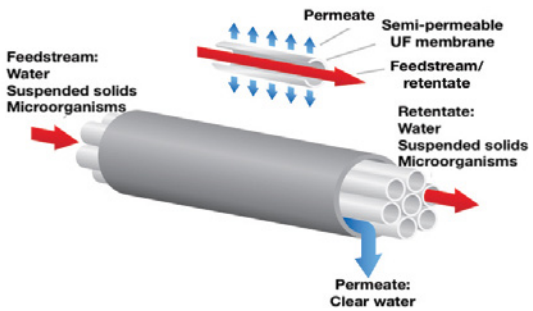

FIGURE 5. There are several operating parameters that impact the performace of tubular membrane-filtration systems

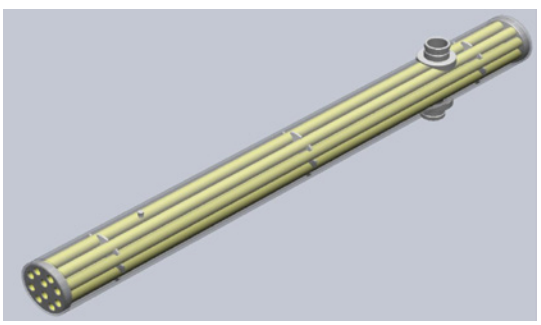

FIGURE 6. The internal elements of a typical tubular membrane module are shown here

Parameters and performance

Before we can fully compare the performance of traditional clarification and settling systems with membrane-based processes, we must understand the operation of tubular membranes. Figure 5 illustrates the typical operational configuration of a tubular membrane module, and the following are four key parameters that control the performance of tubular membrane-filtration systems:

1. Membrane pore-size rating — too large a pore size can lead to rapid mechanical blinding of the pores, resulting in fouling
2. Crossflow velocity — if this is too low, an increasingly dense cake (gel layer) can build up on the membrane surface, causing fouling and low permeate flow
3. Transmembrane pressure (pump pressure across the membrane) — generally, higher values here produce more permeate flow (flux), but more rapid fouling
4. Temperature — increased temperature produces increased flux rate (corresponding to decreased surface tension and viscosity)

Table 1 provides a review of the relationship between various MF membrane parameters. The term "retentate" in Figure 5 identifies the stream that has not passed through the membrane. It contains all of the contaminants rejected by the membrane. This term is synonymous with "concentrate" and "reject." Figure 6 represents a typical tubular membrane module in cutaway view.

Filtration vs. clarification

Because the removal of the precipitated solids in the membrane separation process is absolute filtration (a function of pore size), it is capable of much finer filtration than clarification.

Upsets in clarifiers are well documented and can create events that foul downstream RO processes, often resulting in the membranes requiring chemical cleaning or even replacement. Such issues are nonexistent with the membrane process. The only way that suspended solids can get through the membrane is a catastrophic failure of the MF/UF membrane. This is very unusual.

Below are some additional comparison points between traditional clarification and MF/UF processes:

- Clarifiers require a large footprint. In general, the membrane process footprint is one-third to one-half that of a gravity clarifier
- In most cases, a highly automated MF/UF system is easier to operate and more user friendly than clarification, which requires an experienced operator to maximize the system performance and minimize solids upsets
- A polymer is often used in a gravity settling process to promote flocculation and the formation of a sludge blanket. This is not needed in the membrane process, as solids separation is performed entirely by the membrane
- Capital costs of larger systems are generally higher with the membrane system, whereas they are usually lower for smaller systems. Energy costs are greater with the membrane process due to the high pumping volume required to achieve turbulent-flow velocities across the membrane surface to maximize flux rate and minimize fouling

Table 2 summarizes some of the main differences between the two processes. For total treatment systems with water sources requiring pretreatment to control slightly soluble salts (including Ca, Mg, Si and heavy metals), this membrane technology offers significant advantages.

Total treatment systems

In many applications, the pretreated water needs "polishing" to remove salts or low-molecular-weight organic contaminants that cannot be removed with MF/UF technologies.

The most common polishing technology is RO, and as previously mentioned, this process most frequently utilizes spiral-wound membrane elements (Figure 1). This construction is the least expensive in terms of membrane area. However, it cannot be backwashed to remove foulants from the membrane surface. The tubular

TABLE 2. A COMPARISON OF CLARIFICATION TO MEMBRANE FILTRATION

Conventional (gravity settling) clarifier	Membrane filtration system
Solids carryover when treatment process is upset	Membrane is positive barrier for solids
Solids carryover is negatively affected by increased temperature	Increased temperature tends to increase flowrate
Polymer addition needed	No polymer required
Stabilization time period required for startup	Automatic on and off operation

MF/UF membranes discussed previously can be readily backwashed. This characteristic alone makes tubular MF/UF membranes invaluable for many applications, such as wastewater recovery and reuse. In many of these applications, the wastewater contains high concentrations of suspended solids and dissolved organics that are capable of irreversibly fouling RO membranes.

As stated previously, the utilization of membrane technology for the treatment (and concentration) of pH-adjusted industrial wastewater streams is virtually the same as for groundwater sources (raise the pH, treat with tubular membranes and dewater the concentrate stream). Therefore, this treatment approach is effective over a wide range of applications.

A practical example

The authors both have many years of experience in the design, construction and operation of wastewater recovery and reuse systems utilizing membrane technologies. For example, they recently consulted in the design and construction of a total treatment system originally designed to treat well water for a large recreational facility utilizing an inefficient treatment system. The new system treated the wastewater discharge from the original system by recovering the precipitated hardness salts with MF technology and a filter press, polishing the MF permeate with RO and employing crystallization and evaporation technologies to produce dry solids for landfilling — the result was a zero liquid discharge (ZLD) system. ■

Edited by Mary Page Bailey

Note: All figures provided by authors

Authors

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Wastewater Treatment: Three Steps to Achieving Discharge Compliance

To ensure that wastewater discharge meets all compliance requirements, plants should adopt a multi-tiered approach, rather than assuming that the downstream treatment facilities can handle all potential contaminant loads

Peter E. Norman
SUEZ — Water Technologies & Solutions

Most industrial manufacturing facilities are required to meet strict limits on various contaminants in order to discharge wastewater. Wastewater treatment facilities (Figure 1) remove the specified contaminants, but achieving compliance with local and federal regulations involves more than just installing and optimizing wastewater treatment units. Treatment, or contaminant removal, is just the last stage of a three-step strategy to ensure compliance. A wastewater treatment facility can rarely be designed to successfully treat all possible combinations of flow and contaminant concentrations that could come from a manufacturing operation. Cost expenditure and space requirements alone would make this single-stage approach prohibitively expensive. Reliable environmental compliance can only be achieved by adhering to a regimen combining the following stages:

1. Good source control
2. Equalization and isolation
3. Contaminant removal

Stage 1: Source control

Source control, or waste minimization, is the first stage of the process of preventing the discharge of process contaminants from wastewater. Historically, process operations were not considered part of this strategy. The belief was that the wastewater treatment plant (WWTP) had to handle whatever was released from the manufacturing units. This has often been proven to be a failing strategy. From a plant-operations perspective, waste minimization also makes sense. These materials represent an operating cost to the facility, and overall profitability requires minimizing the waste of valuable raw materials.

From a wastewater troubleshooting perspective, identification of the source of the release is important. Knowing the source helps to rapidly identify the potential contaminants, greatly helping with downstream handling. It will also facilitate root-cause analysis, which decreases the chance of future releases. To do this, appropriate monitoring instrumentation should be installed early in the wastewater handling system — for instance, at sumps at each manufacturing unit. This provides an early warning for the next stage, as well as notifying process operators that a release is occurring. Too many plants still rely on manual communication of manufacturing upsets to the WWTP staff — an approach that is often inadequate.

The choice of instrumentation will depend on the nature of the process at each unit. It could include simple instruments — such as devices to monitor and control temperature, conductivity or pH — or more complex devices like total organic carbon (TOC) analyzers. This allows identification of the specific source of each release, allowing minimization efforts to be targeted cost effectively. It also provides an early warning to downstream processes of the nature and quantity of the release.

FIGURE 1. A typical wastewater treatment facility is not designed to handle all possible combinations of contaminants, so a multi-stage treatment regimen may be helpful in achieving discharge requirements

Stage 2: Equalize and isolate

The second stage of the process to prevent non-compliance comprises one or both of inline equalization and offline isolation of excessive contamination. This stage is necessary to smooth out the variability in loading to the third stage of contaminant removal, and is typically implemented as tankage that stores and dilutes short spikes of contamination, smooths out flow surges, neutralizes pH extremes or temporarily stores offline high-contaminant loads.

This storage-focused stage is often overlooked, but it is a critical component of an environmental compliance strategy and should be maintained and operated as such. Each type of tank serves a somewhat different objective, and the original design of

FIGURE 2. Secondary treatment systems, such as an activated-sludge process, can be vulnerable to contaminant overloading from upstream processes, especially if the plant has been expanded or altered over time

each should be understood.

Classic inline equalization can be one of two types: contaminant smoothing or flow smoothing. Operation for the former objective is best achieved using a tank setup with a large hydraulic retention time and good mixing. This allows the loading surge to be immediately diluted, providing a steady outlet concentration to the next stage, the WWTP. These tanks can accumulate solids if mixing is inadequate, reducing retention, and thus equalization time. Regular cleaning is required if solids accumulation is a problem.

Flow smoothing, on the other hand, requires spare volume capacity to allow storage of the extra flow volume, with controlled release at normal flowrates. This is important because it allows downstream WWTP equipment to operate within design conditions. The two objectives can be in conflict and so two or more tanks may be required if both situations can occur.

Another type of surge-contaminant handling is offline storage, or isolation. The approach here is to capture and store streams with very high contaminant loads and then either dispose of them separately (offsite), or eventually carry out a controlled release back to the wastewater stream, so that contaminant loading stays within the capabilities of the WWTP.

Stage 3: Contaminant removal

The third and final stage in achieving reliable environmental compliance is the classic wastewater treatment plant itself.

Assuming that the first two stages of contaminant control are working well, the contaminant loadings should be within the design ranges of the WWTP equipment. However, in many cases, manufacturing processes have been expanded, which means they potentially may be releasing higher contaminant loadings than what was assumed in the original WWTP design. Examples of increased loading can be found in the overall flow and the amount of solids (TSS, oil) or soluble organic materials (oxygen demand).

In such cases, reliable performance can still often be obtained with adjustments to operation, chemical feed or supplemental equipment. It is recommended that the original design of each unit be clearly understood, so that the optimal operational revision can be implemented.

The flow and solids-handling capabilities of solids-separation units, such as clarifiers, can often be extended with the use of modern chemical-clarification aids, such as coagulants and flocculants. Close control of chemical additives is essential to the optimization of contaminant removal, especially when units are operating at or above design levels. Best practices include pacing all chemical feed systems to flow, ensuring that dosage amounts remain constant as flow changes. Other chemical-feed automation practices include feed-forward and feed-back control, for instance, using TSS or turbidity as the controlled parameter. Not all additives can be easily automated, however, so manual testing often still has to be completed on a regular basis to ensure optimal treatment. Jar testing is one such manual method.

Secondary treatment systems, such as activated-sludge biological systems (Figure 2), are often the most vulnerable to overloading and variability in loading. This vulnerability poses the largest risk to environmental compliance because it is typically the last step before discharge.

Better monitoring is also useful in optimizing the WWTP. Advanced instrumentation allows faster response when parameters start drifting away from control. For example, many primary treatment units are solids separation devices that can benefit from online effluent-turbidity monitoring.

Secondary systems are harder to bring back to optimal conditions after upsets. As such, these systems benefit more than any other part of the WWTP from comprehensive monitoring. The monitoring of critical operating parameters like pH and dissolved oxygen should be online. Other parameters, such as sludge settleability, can be done by operators using grab samples on a daily or shift basis, where instrumentation is not implemented. Biological parameters can be very useful in spotting early signs of stress. These include the routine use of microscopy, as well as more modern monitoring techniques, such as those based on adenosine triphosphate (ATP) measurements.

It can take weeks to recover from a major toxic load to a secondary system, which is the last line of defense before discharge. Therefore, good Stage 1 and Stage 2 operations are integral parts of achieving reliable operation in the secondary system and the entire WWTP.

Effective and reliable permit compliance and pollution control depend on a comprehensive three-stage strategy of waste minimization, or source control, waste equalization or isolation, and contaminant removal in the wastewater treatment plant. In addition, comprehensive monitoring of water quality and operational parameters, utilizing online instrumentation where feasible, are critical to providing reliable compliance. ■

Edited by Mary Page Bailey

Author

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Safety Relief Valves: Installation and Maintenance

Using proper installation practices and adhering to maintenance schedules helps ensure reliable operation of safety-relief valves

Tim Turner and John Kirk
Advance Valve, Inc.

Safety-relief valves are critical components of any pressurized system. In fact, a functioning safety-relief valve could be the most important piece of equipment on a process pressure vessel or pipeline. These valves essentially represent the last line of defense if something goes wrong in the process. If safety-relief valves are not functioning properly and can no longer achieve what they are designed to do, catastrophic failures can ensue, potentially causing significant financial burden, as well as putting lives at risk. Because of the potentially catastrophic consequences of relief-valve failure, adhering to recommended or mandated maintenance schedules, along with ensuring that proper installation practices are followed, is of utmost importance.

Installation issues

Several factors must be considered during the installation of a safety-relief valve. First is the compatibility of the inlet and outlet connections of the safety-relief valve with the vessel or piping to which it is connected. There are instances where the valve is not compatible with the existing connections. Note that the inlet connection of a valve cannot be larger than the mating connection size that is available on a vessel or line. On the discharge side, the connection on the outlet of a valve cannot be mated to a connection that is smaller.

Another common issue arises as a result of a misunderstanding about vertically versus horizontally oriented valve installation. It is important to understand that vertical (referring to vertical valve stem) installation is critical on most safety-relief valves. Most manufacturers do not recommend a horizontal installation, but there are some that seem to be ambiguous regarding this issue. If available, refer to the installation manual for the valve, but in general, vertically oriented installation is preferred in most cases. Horizontal installation presents challenges because when the valve sits sideways, it can allow a place for dirt to gather at a critical location within the valve. This can ultimately prevent the valve from reclosing, even after the slightest overpressure event. When installed in a proper upright position, the valve has no place for sediment to collect and thus, it will be less likely for debris to get caught between the seating surfaces and cause leakage or damage to the sealing surface. Failures of safety-relief valves due to this type of improper installation continue to occur.

Another important consideration for safety-relief valve installation is the match between the category of application and the type of valve: the proper type of valve must be installed for the correct service application. There are three main categories of applications for safety-relief valves: air/gas, steam and liquid. All three applications have separate ASME (American Society of Mechanical Engineers; www.asme.org) code certifications, and while some valves are engineered for, and can be applied to, all three services, the valves can only be code-certified for one type of service at a time. For example, it is not recommended to use a valve that is code-certified and designed for liquid, in a steam application.

Regarding safety valves specifically for steam service, a quick installation tip involves a special fitting called a drip-pan elbow (DPE), used to collect and properly drain the condensate created during an overpressure event (Figure 1). This fitting is mounted as closely as possible to the discharge of the valve. As the steam is escaping through the external piping, much of it will cool and turn to liquid, where it runs

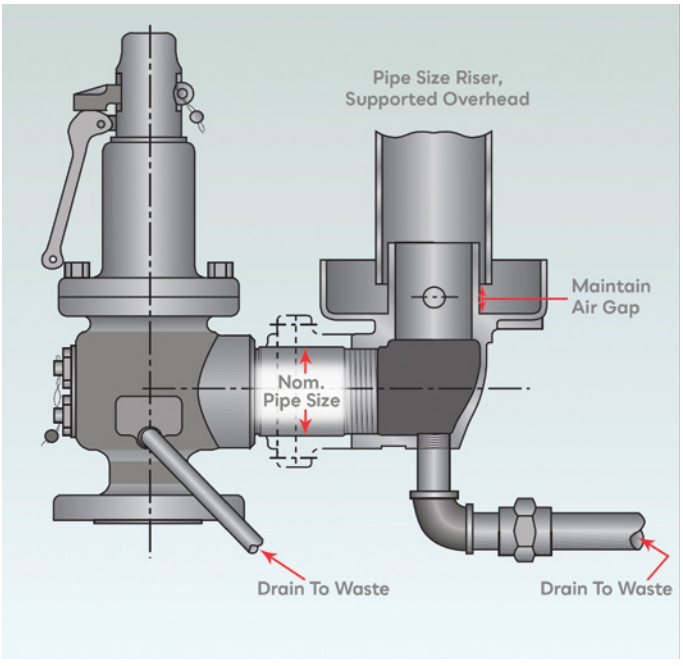

FIGURE 1. Drip-pan elbows, such as the one shown here, collect and drain condensate (Image courtesy of Kunkle Valve, Inc., a Division of Emerson)

TABLE 1†. SUGGESTED TESTING INTERVALS FOR SAFETY-RELIEF VALVES	
Service	**Inspection Type/frequency**
Power boilers less than 400 psi (2.76 MPa)	Lift lever test every six months, set pressure test annually or prior to planned boiler shutdown
Power boilers 400 psi or greater	Set pressure test every three years or prior to planned boiler shutdown
High-temperature hot-water boilers*	Set pressure test annually
Low-pressure steam-heating boilers	Lift lever test quarterly, set pressure test annually prior to heating season
Organic fluid vaporizers	Remove, inspect and set pressure annually
Hot-water-heating boilers **	Lift lever test quarterly, set pressure test annually prior to heating season
Water heaters***	Lift lever test every two months, remove and inspect temperature probe for damage, buildup or corrosion every three years
Pressure vessels / piping-steam service	Set pressure test annually
Pressure vessels / piping air / clean, dry gas	Set pressure test every three years
Pressure vessels / piping propane / refrigerant	Set pressure test every five year
Pressure-relief valves in combination with rupture disks	Set pressure test every five year
All others	Per inspection history

***NOTE 1:** For safety reasons, removal and testing on a steam test bench is recommended. Such testing will avoid damaging the pressure-relief valve by discharge of a steam-water mixture, which could occur if the valve is tested in place.

****NOTE 2:** The frequencies specified for the testing of pressure-relief valves on boilers is primarily based on differences between high-pressure boilers that are continuously manned, and lower-pressure automatically controlled boilers that are not monitored by a boiler operator at all times. When any boiler experiences an overpressure condition such that the pressure-relief valves actuate, the valves should be inspected for seat leakage and other damage as soon as possible and any deficiencies corrected.

*****NOTE 3:** The temperature probe shall be checked for the condition of the coating material and freedom of movement without detaching. If the probe pulls out or falls off during inspection, the valve shall be repaired or replaced. Due to the relatively low cost of temperature- and pressure-relief valves for this service, it is recommended that a defective valve be replaced by a new valve if a repair or resetting is indicated.

† This table was adapted from the National Board Inspection Code, Part 4, and was reprinted with permission from the National Board of Boiler and Pressure Vessel Inspectors

back down the pipe. The job of the DPE is to collect the liquid condensate and drain it away, so that it does not back up into the valve. It is recommended in most steam installations. The only situations where it may not be used is if the steam contains other chemical vapors that might not be allowed to vent directly to the atmosphere. DPEs are also not needed or recommended for air/gas or liquid applications.

Finally, it is important that the safety-relief-valve discharge piping be properly supported. If too much weight is placed on the valve after installation, not only will it not function properly, but depending on the valve materials of construction, the valve body may even distort. Operators may believe that there is a defect with the valve, when in fact, it is a problem with the installation. Depending on the setup, the discharge piping may need to be supported with an external support system to prevent this from happening. In steam applications, the above-mentioned DPE, when properly installed, will help to isolate discharge piping stress from affecting the safety-valve body.

Valve maintenance practices

There are several factors that can affect best practices in terms of maintenance of a safety-relief valve. The biggest question most people have is: "How often do I need to test my valves to make sure they are performing correctly?" Fortunately, many companies have a maintenance schedule in place that addresses this question. Typically, the nature of the process has the biggest impact on this schedule. The questions to be asked are: "What exactly is the application? And how severe are the service conditions?" The answer to these questions will determine the maintenance schedule and ultimately, the testing frequency for the valves.

The more critical the application and the higher the risk associated with the safety-relief valve being non-functional, the tighter the preventative maintenance schedule should be. In addition, testing and maintenance requirements from the owner's insurance company, state and local inspections and other regulations, may play a substantial part in dictating a regular maintenance schedule on these valves. As a general guideline only, the National Board of Boiler and Pressure Vessel Inspectors (Columbus, Ohio; www.nbbi.org) publishes a suggested testing interval for safety-relief valves (Table 1). Again, these intervals should be adjusted based on each user's particular process details, application and experience.

In the petrochemical industry, the valves inserted into most processes will see much more harsh service conditions than those found in many other industries, such as the food-and-beverage sector. There may be certain instances where plant-outage timeframes might be too tight to have the safety valves repaired or replaced. In those cases, it is particularly important to keep spare valves on site for critical applications. In these situations, it may be possible to service them on a more frequent basis. However, this may not always be feasible based on the application. Across the board, many companies are now carrying a smaller spare parts inventory than they once did. Unless the application is critical, they may not necessarily be stocking a spare valve.

In these situations, having a preventative maintenance plan and taking full advantage of scheduled shutdowns is critically important. The maintenance on valves during a scheduled outage is much less expensive than maintenance during an emergency outage. Not only will the expedited repair costs rise during emergency situations, but the downtime experienced by the operation

— and the lost revenue associated with this — can be devastating.

During scheduled maintenance, valves are typically sent to an ASME- and National-Board-certified testing facility. When tested, if a valve falls within the recommended set pressure on the affixed data plate and is not leaking, it will be deemed properly tested on that date and approved for use. However, if the valve fails the set pressure, has issues with sticking open, or is leaking severely, the valve will have to be disassembled and repairs will need to be made. In these situations, the valve internals are inspected, checked and refurbished or replaced with only OEM (original equipment manufacturer) parts to return the valve back to precise working condition.

Some valves are more prone to failure due to their age. In fact, many safety-relief valves in operation have been in use for decades. As with any product, the older the valve, the more difficult it becomes to service, due to reduced general availability of OEM parts or to simple obsolescence.

There are circumstances, however, when a safety-relief valve will fail while in use, and the common indicator is leakage. When there is process media leaking from the valve on a constant basis, while under its normal operating pressure, a repair or replacement needs to happen quickly. Keep in mind that the price of a repair is usually a fraction of the cost of purchasing a new valve. If the valve is just beginning to weep or leak, a judgement call needs to be made: "Can we wait until the next scheduled shutdown to address the valve's issues?" If the normal system-operating pressure is near the set pressure of the valve, and the leak prevents the system from maintaining the necessary operating pressure, then the valve needs to be repaired immediately.

When servicing an ASME-certified valve, any required replacement parts must be purchased either directly from the OEM or from an authorized distributor for the OEM. All valve manufacturers must supply information on tolerances and critical valve dimensions to National Board-certified repair shops in order for proper repair and testing to take place. It should be emphasized that a National Board "VR" certified facility is the preferred choice.

The National Board Inspection Code (NBIC) does allow for operators who hold a "VR" stamp to have their maintenance personnel repair and recertify their own valves. However, some operators many not be as well-versed in valve repair as a dedicated "VR" shop, because their plant may contain numerous valves from a variety of manufacturers. The biggest mistake a plant can make is to have its valves repaired by a non-certified facility. With this approach, an operator heightens the risk of catastrophic failure.

In summary, safety-relief valves are critical pieces of equipment that must be installed properly, and regularly maintained and tested by repair shops that are certified by the National Board of Boiler and Pressure Vessel Inspectors. Failure in any of these areas can result in catastrophic failures that will ultimately cost the owners and operators money and even worse, possibly risk the safety of employees. ■

Edited by Scott Jenkins

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John Kirk is a technical sales specialist at Advance Valve (same address as above); Kirk has 20 years of experience with Advance Valve, which, for nearly 50 years, has provided exceptional customer service, ASME-Code-certified safety-relief valves spanning multiple manufacturers, and National Board "VR" valve repair services.

Show Preview

Organized by The Water Environment Federation (Alexandria, Va.; www.wef.org), this year's Weftec conference and exhibition is taking place October 8–12 in New Orleans, La. Focusing on the water and wastewater industries, the event will feature a large exhibit hall, an extensive technical conference, interactive workshops and more. This show preview covers a small selection of the products that will be displayed at Weftec's exhibit hall.

New energy-saving screw blowers for industry

New sizes in the Delta Hybrid line of screw blowers (photo) are designed with smart features that can realize energy savings as high as 30% compared to a conventional positive-displacement blower. Screw blowers are primarily designed for oil-free conveying of air and are suitable for many key industrial applications, from pneumatic conveying and homogenization to wastewater treatment. The blowers are equipped with an innovative compressor stage with new high-efficiency screw profiles and internal flow optimization. This is coupled with motors of energy-efficiency class IE4 as standard, optimized guiding of cooling and exhaust air, as well as a self-tensioning belt drive with an efficiency of over 98%. An effective sealing concept for the driving shaft and conveying chamber minimizes natural wear and also guarantees oil-free operation in accordance with ISO 8573-1 Class 0. The patented reactive silencer requires no absorption material and successfully prevents contamination of process air or of the downstream process system. This is a decisive factor for reliable operation in the food or wastewater-treatment sectors. Booth 843 — *Aerzen USA Corp., Coatesville, Pa.*
www.aerzen.com

Completely redesigned control valves to be launched at Weftec

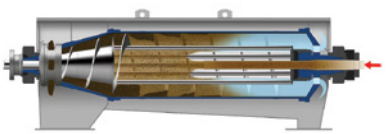
This company is launching a completely redesigned and technically revised Iris diaphragm control valve (photo) into the North American market. This new series — named IBS — will be presented to a wide audience for the first time at this year's Weftec. The new valves have a compact structure with a shorter installation length. To aid plant operators in knowing valve positioning, a visual position indicator has been completely revised to be visible from three sides of the valve. The self-lubricating spindle nut design of the IBS enables maintenance-free and cost-extensive operation, thus simplifying the use of the control valve in inaccessible locations. An additional advantage is that operators can replace the drive support without having to remove the valve from the pipe. Its gas-tight design has no spindle feedthrough. Self-cleaning segments also make the valve a reliable regulator for handling raw sewage or sludge, as well as process water, primary and aerated sludge, and also for the task of loading centrifuges with digesting sludge. The three buffer-liquid and flushing connections of the new IBS are offset by 90 deg and can also be used for drainage and emptying condensate, which is a major advantage for plants that are shut down periodically. Booth 4008 — *Egger Turo Pumps North America, Inc., Juliette, Ga.*
www.eggerpumps.com

New centrifuge is designed for biosolids dewatering

Xelletor (photo) is a new open-scroll centrifuge technology for water treatment application. Optimized for dewatering of biosolids, the Xelletor's new design enables higher capacities, drier cakes and lower polymer consumption, says the company. Drier cakes mean lower transportation costs, and the Xelletor can provide cakes with 10% lower volume by delivering 2% higher total dry solids. Depending on the capacity of the plant, a 1% increase in dry substance in the dewatered sewage sludge can represent significant cost savings. Xelletor also delivers polymer cost savings by using up to 20% less polymer. Furthermore, says the manufacturer, 20% lower energy consumption is expected with Xelletor, as well as higher capacity with up to 15% more throughflow. Booth 2745 — *Flottweg Separation Technology, Inc., Independence, Ky.*
www.flottweg.com

Aerzen

Egger Turo Pumps North America


Flottweg Separation Technology

Rotary-lobe pumps with a high power density

Tornado rotary-lobe pumps (photo) handle almost any substance over a wide viscosity range continuously and gently while metering in proportion to speed. They offer a small space requirement and high power density. These rotating positive-displacement pumps are self-priming, valveless and feature two rotary lobes running in a synchronized fashion. The rotation of the rotors creates a vacuum on the suction side, which draws in the pumped product. The rotors displace the product into the pressure area. Two to six cavities are filled per rotation, depending on the number of rotor blades. This enables metering proportional to rotation speed. Because of a unique spatial separation between the pump and the gear chamber, Tornado pumps also maximize operational reliability. Due to the significant free-ball passage and the low speeds, these pumps are insensitive to blockages, clogging and foreign bodies. Varying solids content has little influence on the flowrate as pressure changes. Booth 3629 — *Netzsch Pumps USA, Exton, Pa.*
pumps-systems.netzsch.com

Netzsch Pumps USA

A new ductile iron fitting for buried pipes


GF Piping Systems

The new LOKX system ductile iron fitting (photo) features an internal self-restraining gasket that eliminates pipe-to-pipe and pipe-to-fitting separation, even at high pressures. The push-on style fitting eliminates the need for any bolts or external restraints, saving up to 80% in installation time and labor costs. LOKX is specifically designed for use with this company's C900 PVC and CIOD HDPE pipe in buried applications. The system is manufactured to AWWA C153 specifications with a minimum working pressure of 350 psi. Engineered with a deep-bell design, the LOKX system has deflection capabilities of up to a total of 10 deg in any direction (5 deg deflection per bell). This flexibility allows for extreme ground movement, making it suit-

able for seismic applications. The self-restraining gasket has a low insertion force in addition to a lip-seal design with 316 stainless-steel gripping segments. When fully engaged, these segments form a 360-deg restraint that prevents the pipe distortion and point loading that other types of restraints can cause. The leak-resistant LOKX system can be used for a variety of buried applications in water and wastewater, seismic areas, corrosive regions, coastal areas with brackish soils and horizontal directional drilling. Booth 6713 — *GF Piping Systems, Inc., Irvine, Calif.*
www.gfps.com/us

High-precision valve control with versatile automation capabilities


AUMA Actuators

Compact Profox actuators (photo) offer high-precision valve control in water treatment applications requiring fast and precise positioning, utmost flexibility and Fieldbus/Industrial Ethernet interfaces, including installations in mobile containers or module skids. Built-in intelligence makes Profox devices equally suited for open-close duty and modulating applications. Adjustable speed ensures fast and precise positioning. Operating costs are low, thanks to high mechanical efficiency and low standby energy consumption. The actuators work with gate, butterfly, ball and globe valves. Modular design ensures flexible configuration, rapid delivery and consistent operation. Profox actuators are simple and easy to use, with rapid installation and commissioning via pushbuttons or a smartphone app. Actuator status is always clearly visible, even from a distance. IP67 protection (IP68 optional) and the compa-

Blue-White Industries

De Nora Water Technologies

Duperon

Bedford Reinforced Plastics

ny's unique corrosion protection ensure long life even under the toughest process conditions, at temperatures from –30 to 70°C. Booth 5046 — *AUMA Actuators, Inc., Canonsburg, Pa.*
www.auma.com

Wall-mounted pump skids pack many features in a compact model

This company's new Chem-Feed space-saving, wall-mount skid systems (photo) provide a convenient, fully assembled alternative to bulky floor models by freeing up valuable floorspace. Chem-Feed wall-mount skids are available in simplex or duplex chemical feed-pump configurations and are built to deliver chemical resistance, with four pipe material options, including PVC, CPVC, PVDF and Chem Proline. All skids are fusion-welded for added strength, and plumbing connections are threadless for leak-free operation. These skids have a lightweight, chemical-resistant polyethylene back panel with built-in holes for easy access to wiring. In addition, there are four conveniently located handles to assist with installation. Booth 1917 — *Blue-White Industries, Inc., Huntington Beach, Calif.*
www.blue-white.com

UV systems tackle contaminants of emerging concern

Capital Controls UV systems (photo) treat groundwater, wastewater and drinking water using conventional ultraviolet (UV) disinfection and advanced oxidation process (AOP) solutions. UV light alters the DNA of harmful organisms without the use of chemicals, rendering pathogens unable to reproduce and cause harm. Capital Controls UV systems can be packaged with other oxidant generators for advanced oxidation process (AOP) treatment to tackle complex applications and contaminants of emerging concern. Systems are designed using computational fluid dynamics analysis for optimum performance and independent third party-certified UV intensity sensors for accurate delivery of UV dosage. Safe and reliable, all systems feature automatic emergency shut-down system and robust long-life electromagnetic ballasts with superb voltage tolerance. Small footprint designs allow simple retrofit to existing plants and fully automated control system with automatic quartz sleeve provide ease of operation. Booth 2701 — *De Nora Water Technologies, LLC, Sugar Land, Tex.*
www.denora.com

A new screening system with more hydraulic capacity

FlexRake IQ2 (photo) is a screening system that performs fine screening during normal conditions, then automatically transitions to a wider opening during peak conditions. The FlexRake IQ2 significantly improves solids handling by sensing conditions and speeding up to accommodate changing debris and flow. The reconfigured geometry of design allows for the lowest possible engagement to better handle settled solids. Re-engineered scrapers remove up to four times more debris than predecessor models. The re-imagined FlexLink still manages large debris without jamming and now re-engages into the bar screen faster. For optimum performance under all conditions, the FlexRake IQ2 intuitively transforms the bar screen to accommodate increased flow capacity without operator intervention. Furthermore, the FlexRake IQ2 provides additional resilience with the safety factor of a coarse screen combined with the debris capture of a fine screen. Booth 5349 — *Duperon Corp., Saginaw, Mich.*
www.duperon.com

Modular safety structures made of fiberglass-reinforced plastic

ReadySeries is a broad lineup of fiberglass-reinforced plastic (FRP) modular safety structures designed to meet access and safety structure needs. A solution for meeting industrial safety needs quickly and affordably, ReadySeries structures are OSHA compliant. Unlike wood and metal, ReadySeries FRP is fire-retardant, corrosion-resistant and non-conductive. Anti-slip coatings minimize fall and slip risks. The ReadySeries system includes industrial platforms, mezzanines, walkways, catwalks, fixed ladders, handrails, guardrails, stairs, stair towers and more. Booth 6151 — *Bedford Reinforced Plastics, Bedford, Pa.*
www.bedfordreinforced.com ■

Mary Page Bailey

Show Preview

Every three years, the world of plastics and rubber meet in Düsseldorf, Germany. From October 19 to 26, 2022, the world's leading trade fair K presents new products and innovations from all sectors of the industry — from production to processing to mechanical engineering. Once again, the central point of contact for the critical exchange of information, thoughts and opinions is represented by the Special Show, Plastics Shape the Future, in Hall 6. The focus of the special show under the auspices of Plastics Europe Deutschland (PED), the plastics producers' association, and Messe Düsseldorf will be on the three groundbreaking hot topics of K 2022: climate protection, circular economy and digitalization.

The following is a preview of some of the products being exhibited.

A small extruder system for development work

This company's smallest extrusion system is the laboratory roller extruder L-WE 30 (photo). This new extruder size was developed for experimental extrusion tests and is a further addition to the proven modular extruder system, which is used in many industrial sectors. It is also suitable for the development of new processes for food and chemicals, because the parts in contact with the product can be made of stainless steel. With the L-WE 30, the advantages of the planetary roller extruder — absolute temperature control, mixing according to the active ingredient, low-shear thin-film rolling and large surface exchange — can now be applied in material-critical areas. Even very small throughput quantities of only a few hundred grams per hour can be produced. Units with efficient and accurate temperature control up to 430°C are manufactured in-house. Hall 16, Stand A42 — *Entex Rust & Mitschke GmbH, Bochum, Germany*
www.entex.de

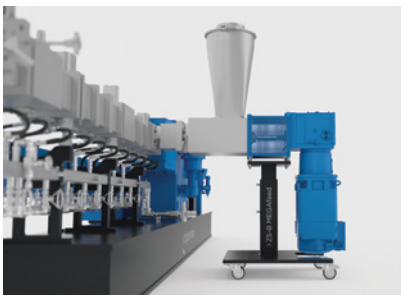
Machinery for recycling different types of plastic

This company is presenting a variety of new and ongoing developments that will markedly increase the efficiency of plastics compounding processes and help boost conscientious resource handling while also achieving very high product quality. Moreover, the company is creating a space dedicated to the forward-looking topic of plastics recycling. The company is exhibiting an entire production line for recycling polyethylene terephthalate (PET) at their booth within the VDMA's Circular Economy Forum, a pavilion on the open-air fairgrounds (CE09). Exhibits will encompass bulk solids handling, feeding, extrusion and pelletizing, all representing numerous plastics recycling processes, such as chemical recycling, multilayer film recycling and upcycling. Trailblazing new developments, such as the ZS-B MEGAfeed side feeder (photo) that enables plastic film and flake recycling in very high throughput dimensions, will be center stage at the company's Recycling Pavilion. Hall 14, Stand B19 — *Coperion GmbH, Stuttgart Germany*
www.coperion.com

Innovative solutions for plastic production

This company is presenting its new deodorizing system for the first time. Deoderization is important when it comes to increasing the proportion of recycled plastics in new production, because the strong odor development of recycled material in some plastics previously precluded its use in higher-value products. The new continuous deodorization systems remove volatile organic compounds (VOCs) from the recycled material via air flushing. The special design for energy recuperation saves a considerable amount of energy. Another highlight is the company's mixing technology. The portfolio includes mixers for every application — from universal and container mixers to horizontal mixers and heating/cooling mixer combinations. One example is the innovative mixing concept of the CMQ container mixer (photo), which enables high-quality mixing results and short cleaning times. Hall 10, Stand C14 — *Zeppelin Systems GmbH, Friedrichshafen, Germany*
www.zeppelin-systems.com

Entex Rust & Mitschke



Coperion

Zepplpelin Systems

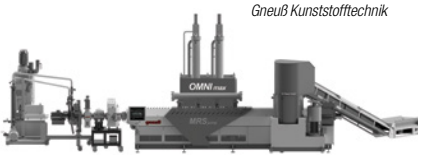
Advanced mixing technology for chemical plastic recycling

Ekato Process Technologies

The goal for efficient plastics recycling needs to not only return pure, but also compounded polymers to a cycle. Thus, chemical plastic-recycling processes must be established on a large scale. Depending on the recycling process, very high viscosities or even higher rheological challenges, such as yield points, are to be expected. Efficient stirring technology is necessary to handle this quite sophisticated combination of mixing tasks. As an example, With the Paravisc impeller system (photo), for example, axial mixing is achieved through the unique shape and arrangement of the two main blades, even managing high product viscosities. Processes with different types of plastic waste can be tested and optimized under realistic conditions on a technical scale in the company's technology center, or in pilot plant. Based on the findings from pilot tests, a complete reactor system can be tailored to the needs of the user. Hall 11, Stand A65 — *Ekato Process Technologies GmbH, Freiburg, Germany*
www.ekato.com

A system to recycle fiber or thermoform reclaim

This company is exhibiting its latest machinery innovations for recycling needs, with a complete OMNI recycling machine (photo), featuring a new 3C rotary feeder an MRSjump 70 extruder, a fully automatic melt filtration system RSFgenius 90 and an online viscometer VIS, for the processing of 200 kg/h of undried and uncrystallized polyester (PET) thermoform reclaim. The newly developed 3C rotary feeder makes it possible to use low-bulk-density materials without any external processing steps. A conveyor belt feeds shredded reclaim material into the hopper, where a fast-rotating disc with knives cuts, compacts and preconditions the material. The knives add energy into the material and start the heating and degassing process before the material is automatically fed into the MRSjump extruder. The MRS extruder is based on conventional single-screw technology, but is equipped with a multiple-screw section for devolatilization. In combination with the company's rotary filtration technology, a high melt purity is guaranteed. Hall 9, Stand A22 — *Gneuß Kunststofftechnik GmbH, Bad Oeynhausen, Germany*
www.gneuss.com



Gneuß Kunststofftechnik

A die plate for underwater pelletizing

In May 2022, this company acquired the French tool manufacturer AMN DPI (AMN), thus continuing its growth as an integrated supplier of systems for the plastics industry. For the first time, a complete AMN Central Injection System (CIS) consisting of a 1,500-mm diameter die plate with a central water injection and sword-shaped knives (photo) will be exhibited at K 2022. CIS was designed to improve pellet cooling and ejection and is an effective solution for high-melt-index or peroxided polymers. Die plates are the heart of the underwater pelletizing system; necessary to produce high-quality and consistent pellets.

Magg Group

Over many years, the unique technologies of AMN die plates have demonstrated their performance and longevity in many applications, especially for high capacity underwater pelletizers. Hall 9, Stand A02 — *Maag Group, Oberglatt, Switzerland*
www.maag.com

Companies joined forces to optimize upcycling

During the live demonstrations, this company and others will showcase how a machine manufacturer, an additive supplier, a recycler and an extrusion blow molding (EBM) equipment provider each play a critical role in enabling lower-value consumer waste to be circulated back into demanding packaging applications. For the demonstrations, PreZero will supply the high-density polyethylene (HDPE) regrind, which was made from consumer waste treated through the company's sorting, washing and grinding processes. The material will then be repelletized on an Intarema TVEplus recycling line, where melt filtration and vacuum degassing are performed under the ideal, gentle conditions necessary to avoid degrading the material. Erema will further demonstrate how a valuable piece of add-on equipment, a KOCH-Technik feeder, can expand the number of potential commercial opportunities. The feeder will be used to introduce this company's Baeropol T-Blend performance-enhancing one-pack additive (photo) into the process. Hall 5, Stand A21 — *Baerlocher GmbH, Unterschleißheim, Germany*
www.baerlocher.com

Baerlocher

Gerald Ondrey

CHEMICAL ENGINEERING
ESSENTIALS FOR THE CPI PROFESSIONAL
Access Intelligence

Water Management

special advertising section

Inside:

Avoid Boiler Performance and Reliability Problems

HRST, Inc. specializes in Heat Recovery Steam Generators (HRSGs) and Waste Heat Boilers. Their engineers, technicians, and designers pride themselves on performing inspections, analysis, engineered upgrades, and outage field services. **HRST**'s services and products help your plant avoid and solve boiler performance and reliability problems. The list below highlights the waterside services provided by HRST:

HRSG Cycle Chemistry Consultation and Metallurgy Analysis

The HRST on-site chemistry assessment includes an in-depth on-site inspection of the plant's current boiler water chemistry program, including online instrumentation, grab sampling, review of chemistry data, and maintenance program.

FAC Risk Assessment and UT Testing

HRST's approach is to prioritize the risk areas within an HRSG so that a client can optimize their monitoring plan by testing the high-risk areas first. Prioritization is performed based on design review, performance modeling, plus our boiler design and field experience.

Deposit Weight Density (DWD) Analysis

Internal tube deposits can lead to tube failures. HRST can determine the best location to take tube samples, analyze the samples and recommend the appropriate follow up action.

HRSG Waterside Chemical Cleaning Consultation

HRST can help you decide if or when chemical cleaning is needed. This service can include proper inspection, sampling location selection, sample lab analysis and location, and design review.

Waterside Borescope Inspection

Problems found with borescope inspection can include FAC, attemperator component cracking, oxide exfoliation, and deposits in evaporator and economizer tubes.

Covered Piping System (CPS) Inspection Program Development

HRST has developed a robust CPS program and document that helps plants satisfy ASME B31.3 code compliance and establish a site-specific CPS program for their steam and water piping.

For more information on HRST's services and products, visit **www.hrstinc.com.**

Avoid costly mistakes choosing vacuum technology

Process standards are one of many factors that influence the selection of vacuum technology. Energy costs, environmental laws, and hazardous waste disposal all influence which vacuum technologies are selected.

Dry screw vacuum pumps vs. other technologies

COBRA dry screw vacuum pumps are a sound choice for those looking for high efficiency while reducing costs generated from operating fluids such as steam, water, or oil. They can consume up to 40 percent less energy than a liquid ring vacuum pump with a smaller footprint and lower water consumption. For applications that require high gas flow at lower pressures, steam ejectors are added to liquid ring vacuum pumps. While the ejector has no moving components, the technology consumes large amounts of energy. To generate the required motive gas for the ejector, water is continuously boiled to produce steam. Similar performance can be achieved with a dry screw vacuum pump system. Lastly, oil sealed rotary vane vacuum pumps use a significant amount of oil to aid in sealing, cooling, and lubrication. For harsh applications, the process gases are exposed to the oil, often requiring weekly oil changes. This leads to high volumes of waste. For the dry screw vacuum pump, oil disposal is minimal because the oil is isolated from the process and only used for gear lubrication. Unlike other technologies, dry screw vacuum pumps can also reach an ultimate pressure of ≤0.01 mbar without requiring additional vacuum equipment. The COBRA vacuum pump outperforms similar vacuum technologies in the chemical industry due to the ability to be customized to fit each chemical process with different coatings on wetted parts, seal types and materials.

A complete vacuum solution vs. a single vacuum pump

Accessories like knock-out pots, inlet filters, condensers, and automation equipment often extend the service life of the vacuum equipment by three times or more. But adding unnecessary accessories is costly and wasteful. Only considering the vacuum pump will lead to more downtime and frequent maintenance. This will add higher operation costs to the vacuum pump, which are often overlooked during the return-on-investment analysis.

A **Busch** vacuum system minimizes installation requirements and provides peace of mind knowing the system has the proper components for long-term reliability and fit-for-purpose.

www.buschusa.com

New Monitor/Controllers Feature 7 Parameters in 1

Myron L Company multi-parameter water quality monitor/controllers are easy to install, easy to use, and do the job of multiple monitors and controllers.

900 Series Multi-Parameter Monitor/Controllers include everything required to simplify water quality management across industrial applications in a single user-intuitive instrument. Simultaneously monitor and control critical water quality parameters through multiple inputs/outputs with the legendary accuracy and reliability the Myron L Company has come to be known for. 900 Series Monitor/Controllers feature a simple-to-use LCD touchscreen Graphical User Interface along with pluggable terminal blocks for quick and easy equipment installation and configuration.

Monitor 7 critical water quality parameters simultaneously from easily configured inputs: 2 Conductivity/Resistivity/TDS/Salinity; 1 pre-amplified pH/ORP; 1 BNC pH/ORP; 1 0-20/4-20 mA; 1 RTD Temperature; and 1 Flow/Pulse. % Rejection is available as a derived value. Conductivity/TDS measurements feature the ability to select from one of three preprogrammed solution modes, KCl, NaCl, or Myron L's own 442 Natural Water Standard, or to program a User solution mode based on a known solution. Temperature compensation is automatic to 25°C or can be disabled by the user as required. The pH/ORP input channel is designed for use with Myron L pre-amplified pH and ORP sensors. These sensors contain precision circuitry that increases accuracy and permits application of the sensors over greater distances. The 0-20/4-20 mA input allows user-defined 0 to full scale values and units of measure for a wide array of sensor types. Electronic or wet calibrations are easy to perform.

Outputs include up to 3 relays; 2 remote alarms; 1 0-20/4-20 mA; 1 0-5/0-10 VDC; and 1 RS-485 ASCII Serial Output. Relays output to any user-supplied control equipment requiring up to 250V each and can trigger on any input parameter. The 0-20/4-20 mA output can transmit a signal for any input parameter. 0-5/0-10 VDC can be scaled to optimize resolution and can output to a recorder, PLC, SCADA system, etc. 0-1 VDC is possible with optional resistor. Hysteresis values can be specified by the user or automatically set by the 900 Series to prevent chatter.

The flow switch input can disable all relay outputs when triggered by loss of flow.

User adjustable cell constant (Conductivity/Resistivity/TDS/Salinity) and sensor cable length (Conductivity/Resistivity/TDS/Salinity, pH and RTD) increase accuracy. Administrator and Operator password protection levels prevent unwanted tampering. The brightly colored red, yellow, and/or blue LCD background instantly alerts the user to the solution status. A $^{1}/_{4}$ DIN Size Chassis makes it easy to mount.

Myron L also backs these instruments up with live dedicated technical support that assures installation and operation success.

www.myron.com

Meet the latest innovation in radar level sensors.

VEGAPULS 6X makes it easier than ever for water and wastewater operations to get precise and reliable measurements

From overfill protection to process automation, level measurement sensors play an important role in the water and wastewater industry. That's why it's critical for water operations to entrust their processes to precise and reliable instrumentation that can tackle the most challenging of applications.

80 GHz radar technology has recently emerged as a step forward for water industry level measurements. Unlike ultrasonic, radar is unaffected by temperature, pressure, or vacuum; radar has no dead zone, allowing safe measurements all the way up to the sensor antenna, even in the case of flooding; and 80 GHz radar's precise signal focusing means the radar beam can be aligned almost exactly with the medium being measured without interference from pipes and pumps, narrow shafts, or deposits on vessel walls.

As much as the introduction of 80 GHz radar level sensors already improved water processes, the measurement experts at **VEGA** found room for further refinement.

In 2020, VEGA introduced a Basic series of VEGAPULS radar sensors designed for simple, cost-sensitive applications, with the needs of the water and wastewater industry in mind. And this year, VEGA launched its latest innovation in the form of its new Pro series radar sensor for more demanding level applications: VEGAPULS 6X.

VEGAPULS 6X is a product of the experience VEGA gained from manufacturing and selling over one million radar sensors; it is one sensor for any level measurement application, liquids or bulk solids. By simply providing the details of their application through VEGA's online configurator, operators will receive a VEGAPULS 6X tailor-made for their needs.

Precision, reliability, and ease-of-use were the guiding principles of VEGAPULS 6X's design. VEGA's latest custom radar chip powering the sensor enables it to measure at a range of 120m (approx. 394ft), with an accuracy of ±1mm. The chip continually monitors the accuracy and performance of the sensor, ensuring reliable performance. And in addition to the easy configuration process, VEGAPULS 6X is easy to set up and use, with Bluetooth capability available for safe and seamless operation from compatible smart devices.

While simple water industry level measurements are capably handled by the Basic series of VEGAPULS sensors, VEGAPULS 6X is the one level sensor water operations need for their more demanding applications. With VEGA's current lineup of 80 GHz radar sensors, it's never been easier for facilities to optimize their processes.

vega.com

CHEM-FEED CD1 Multi-Diaphragm Pump Doses Harsh Chemicals

The CHEM-FEED CD1 Multi Diaphragm Chemical Dosing Pump offers a top performing solution for meeting the challenges of dosing harsh and / or gas forming chemical. Dual Diaphragms deliver full stroke technology that will not lose prime, making CD1 ideal for pumping chemicals that off-gas (Peracetic Acid, Sodium Hypochlorite)

The CD1's exclusive cutting-edge Hyperdrive Technology allows for alternating pumping action between two diaphragms: when one diaphragm is in the suction phase, the other is in the discharge phase which results in near continuous feed and smooth, precise, and dependable chemical dosing. No vapor lock and no lost prime.

The manifold design allows for multiple configuration possibilities. Suction and discharge ports can be positioned on the left and right side of the pump.

CHEM-FEED CD1 is equipped with an energy efficient brushless DC motor that won't overheat and helps achieve a large turndown ratio of 2000:1 for extreme accuracy. CD1 has an output range of .004 - 7.70 GPH / .015 - 29.2 LPH, with a pressure rating of 150PSI / 10.3 Bar.

Additionally, CD1 is engineered for near-zero maintenance. The pump is equipped with Blue-White's exclusive, patented DiaFlex diaphragm, manufactured 100% in-house to ensure a quality product. DiaFlex does not have multiple layers like traditional diaphragms, and experiences zero breakdown or delamination. This exclusive single layer diaphragm is designed to last the life of the pump and eliminates the need for costly rebuild kits.

A sealed enclosure and a display shield protect the pump's easy-to-operate controls from chemical spills and splashes. The durable NEMA 4X / IP66 rated housing of CD1 is constructed Valox® (PBT) & PA12.

The CHEM-FEED CD1 is simple to order, installs quickly and is easy to operate. Pumps are shipping now.

www.blue-white.com

Economic Indicators

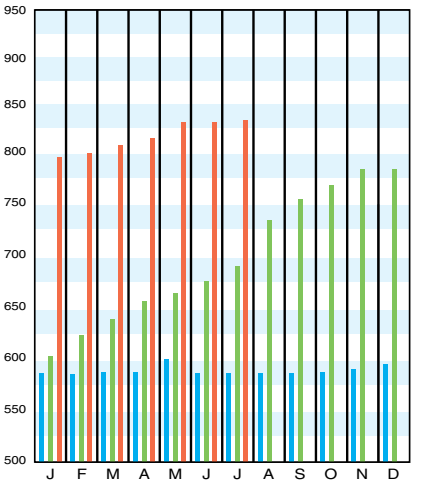
2020 2021 2022

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Jul. '22 Prelim.	Jun. '22 Final	Jul '21 Final
CE Index	829.9	832.6	720.2
Equipment	1054.6	1058.7	896.8
Heat exchangers & tanks	891.0	897.2	767.5
Process machinery	1073.8	1074.4	913.4
Pipe, valves & fittings	1480.0	1497.0	1245.0
Process instruments	558.3	570.5	531.3
Pumps & compressors	1308.5	1285.2	1151.5
Electrical equipment	770.5	767.9	614.5
Structural supports & misc.	1199.5	1189.8	974.8
Construction labor	357.3	355.8	344.0
Buildings	834.3	840.6	765.3
Engineering & supervision	312.0	312.2	310.5

Annual Index:
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2
2021 = 708.0

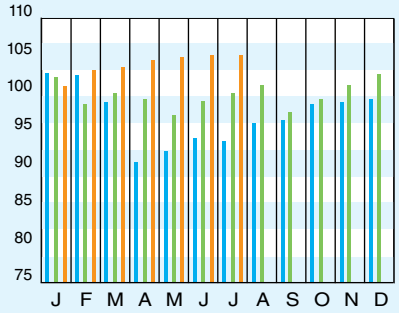


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

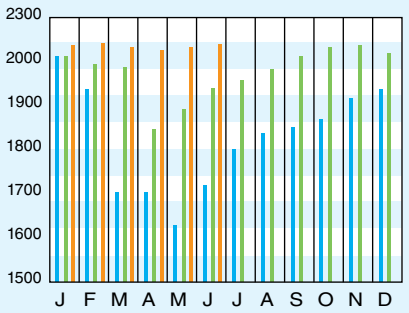
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS	YEAR AGO
CPI output index (2017 = 100)	Jul. '22 = 101.9	Jun. '22 = 101.7	May '22 = 101.9	Jul. '21 = 99.4
CPI value of output, $ billions	Jun. '22 = 2,258.9	May '22 = 2,194.5	Apr. '22 = 2,105.2	Jun. '21 = 1,807.0
CPI operating rate, %	Jul. '22 = 82.5	Jun. '22 = 82.4	May '22 = 82.7	Jul. '21 = 80.6
Producer prices, industrial chemicals (1982 = 100)	Jul. '22 = 383.2	Jun. '22 = 377.3	May '22 = 370.8	Jul. '21 = 320.6
Industrial Production in Manufacturing (2017 =100)*	Jul. '22 = 102.3	Jun. '22 = 101.6	May '22 = 102.1	Jul. '21 = 99.2
Hourly earnings index, chemical & allied products (1992 = 100)	Jul. '22 = 200.2	Jun. '22 = 197.8	May '22 = 198.1	Jul. '21 = 195.8
Productivity index, chemicals & allied products (1992 = 100)	Jul. '22 = 92.7	Jun. '22 = 93.0	May '22 = 92.6	Jul. '21 = 95.7

CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)

*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for July 2022 (most recent available) fell slightly from the previous month's final value, which was downwardly revised by a small amount. The month-to-month decrease is the first in the overall CEPCI value since Septemer 2020. The Equipment subindex, as well as the Buildings and Engineering & Supervision subindices decreased in July 2022, while the Construction Labor subindex climbed slightly higher. The current CEPCI value now sits at 15.2% higher than the corresponding value from July 2021. Meanwhile, the Current Business Indicators for July 2022 (middle) showed a slight increase in the CPI Output Index over the previous month's value.